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ORIGINAL ARTICLES.

I.—Notes on new or imperfectly known Chalk Polyzoa.

By R. M. Brydone, F.G.S.

(*Continued from the January Number, p. 4.*)

(PLATE VI.)

Pseudostege concursa,[1] sp. nov. (Pl. VI, Figs. 1–3.)

Zoarium incrusting, with a tendency to grow in bands: the general surface stands high and shows no trace of zoœcial boundaries; it is much rumpled, apparently unsystematically, but is only broken by the zoœcial peristomes; these are short tubular prominences inclined slightly forwards but bent upwards at the ends so as to end in a plane parallel with the general surface: the apertures are on the whole circular, but very rarely truly so, and occasionally very irregular; they vary in internal diameter from ·08 in a small specimen such as Fig. 2 up to ·15 mm. in a large specimen such as Fig. 3; the peristomes are thick and each has from one to four pores in it; these pores are generally small and round, but occasionally among the larger ones are found definite instances of arrowhead shape which makes it possible that all are avicularian: round the edges of the zoarium there is a fairly complete fringe of simple shallow Membraniporiform zoœcia, with the general surface either ending abruptly above them or sloping gradually down to them.

Oœcia small and globose, perched on or sunk slightly into the anterior part of the peristome, very erratic in occurrence.

Avicularia of two kinds—(*a*) accessory, as above described, (*b*) vicarious, of hour-glass type with the upper lobe much elongated, the lower very short and devoid of internal front wall and indications of a transverse bar at the point of maximum constriction; these occur at or near the edge of the zoarium.

This species is referred only provisionally to *Pseudostege*, as I do not feel confident that the fringe of Membraniporiform zoœcia really represents a primary stage, nor am I clear as to how exactly the general zoarial crust is developed. The species is introduced here because it occurs at the same horizon in Hants, about the junction of the zones of *A. quadratus* and *B. mucronata*, as several of the *Membraniporellæ* I have just been describing, and presents so

[1] The term *Pseudostega* has been used for a division of the Cheilostomata, presumably as a neuter plural. This term is not therefore identical with my genus *Pseudostega* (Geol. Mag., 1910, p. 259), which is a feminine singular, but to avoid any risk of confusion it is perhaps as well to amend my term to *Pseudostege*.

many points of resemblance (apart from the Cribriline surface) to some of them, e.g. *M. thoraceformis* and *M. Shawfordensis* that it seemed bound to be a member of that group with a complete secondary front wall. I have not, however, been able to find any trace of Cribriline structure about it. It seems to lead almost directly to

CELLEPORA (?) DIASTOIDES, sp. nov. (Pl. VI, Fig. 4.)

Zoarium incrusting, consisting of a common crust out of which arise long tubular, slightly barrel-shaped zoœcia, free for the greater part of their length, inclined strongly forwards but sometimes turning erect at the end; they have slightly thickened peristomes, in which there may be from one to three pores, one in the middle of the posterior part being fairly regular; these pores can often be seen in the larger zoœcia to be the apertures of tubuli mainly embedded in the zoœcial wall; the apertures are more or less circular, but sometimes very irregular in shape: the oœcia are very small, globose, perched on the anterior part of the peristome and overhanging the greater part of the aperture: there is a partial fringe of shallow Membraniporiform zoœcia.

This species is fairly common at Trimingham, and is probably to be found in the Norwich Chalk, as I have specimens from Norwich and Weybourne which seem to be inchoate forms of this species. It is so clearly in most respects a development from *Pseudostege concursa* (*ante*) that it is rather surprising that there should be no trace of vicarious avicularia. Apart from the oœcia and the peristomial pores it might easily pass for a sturdy *Diastopora*.

* * *

There is a large group of *Membraniporæ* in which a pair of pores or tubes at the anterior end are repeated with great regularity and another group in which a single tubular prominence occurs very persistently at the posterior end of the aperture. Both are well represented in the English Chalk, and they might be expected to be always easily distinguishable, but this is not the case. I propose to deal with some of the English species of these groups in order of seniority.

MEMBRANIPORA SEAFORDENSIS, sp. nov. (Pl. VI, Figs. 5, 6.)

Zoarium unilaminate, normally incrusting, occasionally free.

Zoœcia of medium size, average length ·5 to ·6 mm., breadth ·4 mm., with thin common side-walls; apertures naturally widely oval, but rendered irregularly polygonal by intrusion of the edges of the more or less rounded protuberances, with small round or elliptical apertures, of which a pair is set with extreme regularity on the front wall of every zoœcium anteriorly to the oœcium; these protuberances appear to be accessory avicularia of the small beak-shaped type in a primitive stage; sometimes they become confluent.

Oœcia occur with very great regularity: they are set on a shelf so deep within the aperture at the anterior end that their tops are little more than flush with, or may even be below, the general surface; their apertures appear to be very strongly cut back, so that the visible top is very much shorter than the basal shelf: the latter is

indicated in a few zoœcia at the top of Fig. 5, from which the œcia have been broken away.

The species is fairly regular in occurrence in the zone of *M. cor-testudinarium* at Seaford. It is fairly intermediate between the published figures of *Flustrina constricta*, D'Orb.,[1] and *F. ovalis*, D'Orb.,[2] but Canu in his "Revision" throws doubt upon the validity of either of these species.

MEMBRANIPORA MULTIFISSA, sp. nov. (Pl. VI, Figs. 7, 8.)

Zoarium unilaminate, incrusting.

Zoœcia of medium size, average length ·5 to ·6 mm., breadth ·4 mm., without any definitely visible interzoœcial sutures; apertures broadly oval, flattened at the anterior end, enclosed by rather rounded margins which approach one another rather closely laterally but are quite distant longitudinally; a pair of rather large sub-tubular pores occur very regularly on the outer edges of the margins just beside the anterior end of the aperture, while between the margins there are numerous irregularly scattered and less pronounced openings, some of which are tubular, while others are mere fissures possibly along zoœcial boundaries.

Oœcia fairly abundant, always broken, semicircular in ground plan.

Avicularia probably of two kinds—(*a*) accessory, represented by the paired marginal pores, (*b*) vicarious, scarce, of hour-glass type, with a long area of constriction, traces of a cross-bar at its lower end, a narrow internal front wall in the short round anterior lobe, and no internal front wall in the small posterior lobe, which has a very slender rim marked off by a little furrow, a feature not brought out by the photographs.

This species occurs in the zone of *M. cor-anguinum* at Gravesend. The relative size of its paired pores, no less than its possession of vicarious avicularia, distinguish it from any figured species, except *M. dolium*, Bryd.

MEMBRANIPORA SEVINGTONENSIS, sp. nov. (Pl. VI, Fig. 9.)

Zoarium unilaminate, free.

Zoœcia large, average length ·7 mm., with oval apertures narrowing considerably to the anterior end, which is flattened by the edge of an inward sloping shelf, and surrounded by raised margins almost in contact with one another and bearing from seven to nine pairs of blunt imperforate denticles, of which those round the anterior end are very slender: at the foot of nearly every zoœcium there is a large, more or less semicircular, hollow thin-walled protuberance, which is probably avicularian; between this and the aperture the raised margin dies away and the tubercles disappear; there are no other indications of avicularia.

Oœcia occurring erratically, shortly and widely conical with rounded ends and a free edge apparently almost straight; when they are present that part of the apertural margin which they embrace does not undergo any depression, but is bare of tubercles; they may push to one side the protuberances of the succeeding zoœcia or cause them to be absent.

[1] Pal. Crét. Franç., vol. v, p. 304, pl. 702, figs. 5–7.
[2] Loc. cit., p. 304, pl. 702, figs. 8–10.

This species was found in the zone of *M. cor-anguinum* at Sevington, in Hants. It has obvious relationship with the figure of *Flustrellaria granulosa*, D'Orb.,[1] but that figure must be quite unreliable, as Canu, in his "Revision", unites the type with *Flustrellaria dentata*, a widely different form.

MEMBRANIPORA SANDALINA, sp. nov. (Pl. VI, Fig. 10.)

Zoarium unilaminate, incrusting.

Zoœcia of medium size, average length ·6 mm. with small oval apertures from ·3 to ·35 mm. in length, tapering considerably to the flattened anterior end and surrounded by broad, rather indefinite inward-sloping margins, which arise out of a common crust rather sharply in the anterior part, but die away posteriorly: at the anterior end there is a pair of small pores high up on the inner side of the margin just behind the end of the aperture, and a pair of tiny pores on the outer edge of the margin at its corners just outside the points from which the oœcium starts: the pair of small pores occurs with very great regularity, and as the pair of tiny pores can almost always be detected when the presence of an oœcium assists the search, it also is probably always present: at the posterior end of the aperture there is, or rather there should typically be, a central hollow protuberance rather like the front half of a sandal, laid with the toe pointing away from the aperture; this is actually the case with zoœcia which do not have to accommodate the oœcium of another zoœcium, and sometimes even when this accommodation has to be provided; but in the latter case, as a rule, the protuberance is displaced by the oœcium and splits into two rather smaller lateral ones.

Oœcia very regular in occurrence, long and helmet-shaped, with apertures cut a long way back.

Avicularia probably of two kinds: (*a*) accessory, the protuberances above described; (*b*) vicarious, rather scarce, of the hour-glass type, elongated and narrow, with very little infold in the centre, no internal front wall in the lower lobe, and an inflated external front wall at the posterior end.

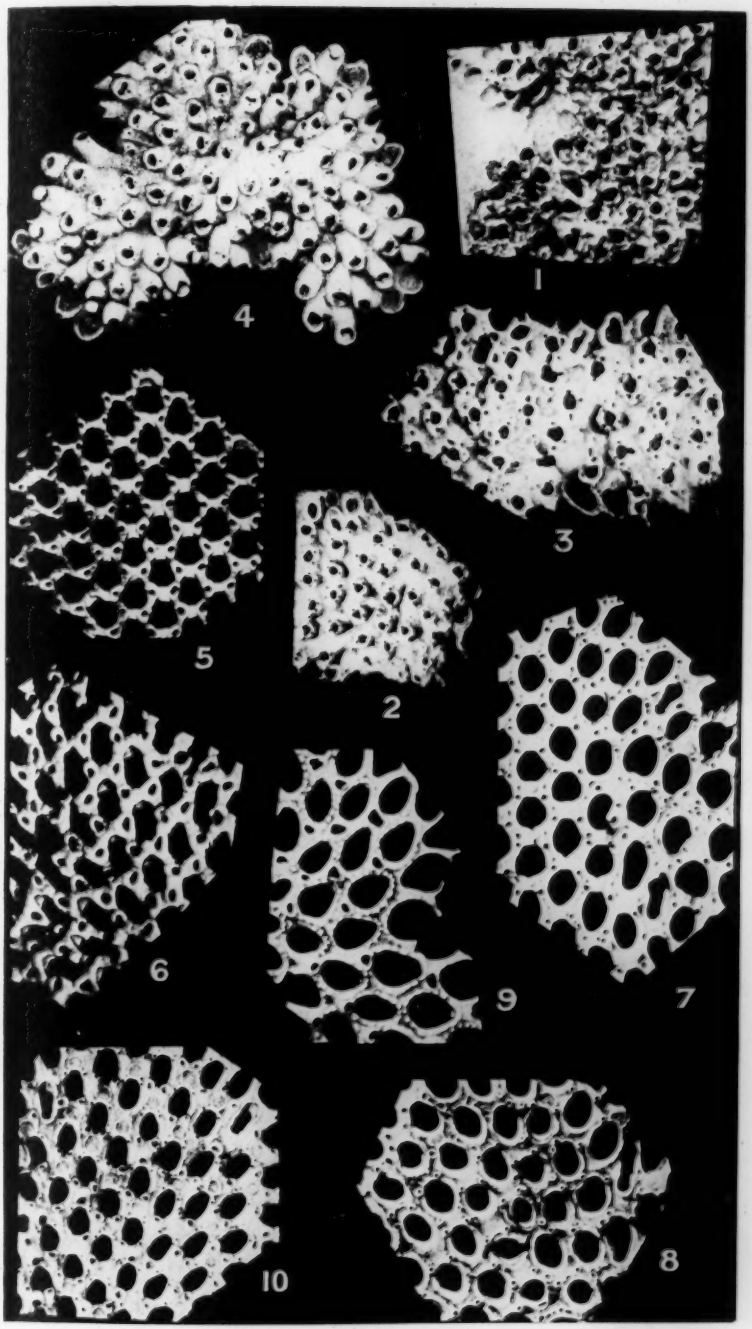
This species, too, occurs in the zone of *M. cor-anguinum* at Gravesend. The two preceding species can obviously be referred to one of the two groups mentioned above. This species not only combines the characters of the two groups, but exhibits an actual passage of the character of the second group into a very plausible imitation of the character of the first group.

EXPLANATION OF PLATE VI.

FIG. (All figures × 12 diams.)

1, 2. *Pseudostege concursa*. Zone of *A. quadratus*. Shawford, Hants.
3. ,, ,, Zone of *B. mucronata*. Portsdown, Hants.
4. *Cellepora diastoides*. Trimingham.
5, 6. *Membranipora Seafordensis*. Seaford, Sussex.
7, 8. ,, *multifissa*. Gravesend, Kent.
9. ,, *Sevingtonensis*. Sevington, Hants.
10. ,, *sandalina*. Gravesend, Kent.

[1] Pal. Crét. Franç., vol. v, p. 525, pl. 725, figs. 1–4.



E. M. Brydone, Photo. Bemrose & Sons Ltd., Collo.

Chalk Polyzoa.

II.—The Lias of South Lincolnshire.

By A. E. Trueman, M.Sc., F.G.S., formerly Research Scholar, University College, Nottingham.

(*Concluded from page 73.*)

BUT while it is difficult to collect fossils in situ in the upper part of the Lower Lias, a very good knowledge of the fauna is obtained from the material which may be collected on the tunnel heaps between Old Dalby and Saxelby. I have been permitted to study the large collection of specimens from these heaps which are preserved at University College, Nottingham, and the Engineer of the Midland Railway Company gave me leave to make small excavations. The following lists give some idea of the fauna, which contains abundant Ammonites, especially of the genera *Tragophylloceras*, *Polymorphites*, and *Platypleuroceras*. The Foraminifera likewise are unusually interesting; a list of genera identified by Wilson has already been given by Quilter[1]; according to the list given by H. B. Woodward[2] no *Textularia*-like form is known from the Lias of any other British locality.

Fossils.

Cf. *Asteroceras sagittarium*.
Acanthopleuroceras cf. *valdani*, d'Orb. (rare).
Cf. *Cymbites lævigatum*, Hyatt (rare).
Deroceras aff. *armatum*, Sow.
Oxynoticeras flavum, Simps.
O. cf. *polyophyllum*, Simps.
O. oxynotum, Qu. (rare).
Platypleuroceras cf. *brevispina*, Sow.
P. aureum, Qu. (abundant).
P. sp. nov. (with knotted venter).
P. rotundum, Qu. (abundant).
P. Birchioides, Qu.
Polymorphites jupiter, d'Orb. (rare).
P. cf. *jupiter*, d'Orb. (common).
P. caprarius, Qu.
P. mixtus, Qu. (abundant).
P. trivialis, Bean-Simps.
P. costatus, Qu.
Tragophylloceras ambiguum, Simps.
T. aff. *numismale*, Qu.
T. loscombi, Sow. (abundant).
T. cf. *ibex*, Qu.
Nautilus intermedius, Sow. (rare).
Belemnites cf. *charmouthensis*, Mayer.
B. acutus, Mill.
Acteonina sp.
Amberleya conspersa, Tate.
Cerithium liassicum, Moore (abundant).
Chemnitzia (?) *semitecta*, Tate.
C. citharella, Tate.
Cryptænia (?) *consobrina*, Tate.
Eucyclus sp.
Pleurotomaria anglica, Sow.
Trochus dalbiense, Wils.
Turbo sp.
Turritella trigemmata, Wils.
Arcomya elongata, Roem.
Astarte cf. *striato-sulcata*, Roem.
Cardinia cf. *lævis*.
Ceromya sp.
Gryphea cymbium, Lam. (abundant).
G. (?) *incurva*, Sow.
Hippopodium ponderosum, Sow. (abundant).
Macrodon intermedium, Simps.
Modiola scalprum, Sow.
M. cf. *hillanoides*, Chap. & Dew.
M. sp.
Nucula sp.
Nuculana (*Leda*) *subovalis*, Goldf.
N. (*L.*) *minor*, Simps.
N. (*L.*) *complanata*, Goldf.
N. (*L.*) *galathea*, d'Orb.
Pecten priscus, Sch.
P. sp. nov.
Pholadomya glabra, Agass. (= *ambigua*, Sow.).
Pleuromya aff. *costata*, Y. & B.
Plicatula spinosa, Sow.
Rhynchonella fodinalis, Tate.
R. lineata, Y. & B.
Spiriferina cf. *Walcotti*, Sow.
Waldheimia lagenalis, Qu.
Cincta numismalis, Qu.

[1] H. E. Quilter, "Lower Lias of Leicester": Geol. Mag., 1886, p. 64.
[2] H. B. Woodward, *Lias of England and Wales*, 1893, p. 377.

Montlivaltia mucronata, Dunc.
M. Haimei, Chap. & Dew.
Extracrinus Britannicus, Sch.
Serpula sp.
Ditrypa etalensis, Piette.
Cytheridea sp.
Holothuroid plates.
Cristellaria cf. *compressa*, d'Orb.
C. crepidula, F. & M.
C. recta, d'Orb.
C. rotulata, Lam.
C. varians, Born.
Dentalina communis, d'Orb.
D. glandulosa, Terq.
D. sp.
Frondicularia intumescens, Born.
F. cf. *Terquemi*, d'Orb.
F. sp.
Glandulina sp.
G. (?) *paucicosta*, Roem.
Lingulina tenera, Born.
Marginulina reversa, T. & B.
Miliolina (*Spirillina*) sp.
Nodosaria radicula, Linn.
N. sp.
cf. *Nonionina* sp.
Orbulina universa, d'Orb.
Textularia sp.

Judging from a less complete list of fossils Mr. B. Smith[1] was able to infer the presence of representatives of the zones from *oxynotus* to *jamesoni*. From the above it is now possible to assert that the beds from Oppel's zone of *A. oxynotus* to that of *A. ibex* are represented. The record of *Deroceras davœi*, Sow., from Old Dalby[2] suggests that still higher beds are present, but the specimen bearing that name in the Leicester Museum, to which the record presumably refers, is wrongly identified, being simply a species of *Lytoceras*.

The association of fossils from such diverse horizons on a single heap, or series of heaps, is rather confusing, but it must be remembered that the material composing the heaps has been accumulated from some two hundred feet of clay, which is approximately the thickness of the zones named in Yorkshire. It was pointed out by Quilter,[3] however, that species are to some extent confined to definite parts of the spoil heaps. Thus, on the lower spoil heap may be found fossils from the *oxynotus* zone, with numerous *Gryphœa*, *Pholadomya*, and Corals, while the upper heap is rich in *Platypleuroceras*, *Polymorphites*, *Tragophylloceras*, and crinoid stems from the *ibex* zone (*valdani* zone of Buckman). The clays on the heaps at the Saxelby end of the tunnel doubtless represent the upper part of the *ibex* zone, but they are less fossiliferous.

The upper part of the Lower Lias (*Oistoceras* sub-zone) is exposed at Waddington Brick Pit, a few yards east of the railway station. About twenty feet of blue shales are here seen, weathered yellow at the top. The nodules are very fossiliferous, each containing one or more capricorn ammonites, chiefly *Oistoceras figulinum*, *O. omissum*, and *O. curvicornum*. "*Androgynoceras*" cf. *capricornum*, Wt., and *Amblycoceras crescens*, Hyatt, are also common. A single specimen of the zone fossil, *Deroceras davœi*, was also found here; apparently this is the most northerly English record for this fossil, which is fairly common in beds of this age in the South of England.

Fossils.

Deroceras davœi, Sow. (very scarce).
Oistoceras omissum, Simps. (abundant).
O. figulinum, Simps. (abundant).
Amblycoceras crescens, Hyatt (not uncommon).

[1] B. Smith, *Geology of Melton Mowbray* (Mem. Geol. Surv.), 1909, p. 37.
[2] C. Fox-Strangways, *Geology of Leicester* (Mem. Geol. Surv.), 1903, p. 108.
[3] H. E. Quilter, "Lower Lias of Leicestershire": GEOL. MAG., Dec. III, Vol. III, p. 59, 1886.

A. sp.
"*Androgynoceras*" aff. *maculatum*, Y. & B.
A. cf. *capricornum*, Wt. (abundant).
Belemnites clavatus, Blainv.
B. milleri, Phill.
Avicula inæquivalvis, Sow.
Leda sp.
Lima eucharis, d'Orb. (rare).
Pecten æquivalvis, Sow. (common).
Protocardium truncatum, Sow.
Rhynchonella cf. *rimosa*, Qu.
Cristellaria crepidula, F. & M.
C. sp.
Dentalina brevis, d'Orb.
D. communis, d'Orb.
D. cf. *nodosa*, d'Orb.
D. glandulosa, Terq.
D. spp.
Frondicularia Terquemi, d'Orb.
F. intumescens, Born.
Lingulina tenera, Born.
Marginulina Römeri, Reuss.
Nodosaria raphanistrum, Linn.
N. sp.
Trochamina sp. (?).

A similar fauna characterizes the lower beds exposed at Bracebridge, a mile north of Waddington, but this section is more conveniently considered later.

3. Middle and Upper Lias.

A. *Lincoln District.*

The best exposure of Middle Lias and contiguous deposits in this area is seen at Bracebridge Brick Pit, about three miles south of the Cathedral, Lincoln, where the following section is exposed:—

		ft.	in.
tenuicostatum sub-zone. 15 ft. 3 in. +	Grey paper shales, weathering orange, with layers of flat, green nodules containing *Inoceramus*. *Dactylioceras* cf. *tenuicostatum*, *D. semicelatum*, *Posidonomya bronni*	15	0
	Impersistent band of dark earthy nodular limestone, with well-preserved *Posidonomya bronni*. "Cone-in-cone" structure		3
acutum sub-zone. 3 ft.	Greenish shale with *Tiltoniceras acutum*, *T. costatum*, *Dactylioceras athleticum*. *D.* cf. *tenuicostatum*, *Leptæna* sp.		4
	Light-grey shale with Dactyloids (*D. athleticum*, *D.* cf. *hollandrei*), *Protocardium* sp., *Goniomya hybrida*	2	8
spinatum zone. 19 ft. 10 in.	Light-grey shale with scattered phosphatic nodules; *Paltopleuroceras* spp.	1	0
	Layer of ferruginous nodules with many phosphatic nodules		6
	Light-grey shales with scattered phosphatic nodules; *Paltopleuroceras* spp.; some beds full of *Protocardium truncatum*, *Dentalium giganteum*, and *Goniomya hybrida*	14	0
	Main Nodule Bed; variable, but usually consists of two beds of brown ironstone separated by green shales with phosphatic nodules. *Pecten æquivalvis*, *P. lunularis*, *Avicula cygnipes*, *Leda* (*Nuculana*) *graphica*, *Belemnites* sp., *Rhynchonella* sp. . . .	2	4
	Grey shales with *Paltopleuroceras* spp. Many Lamellibranchs	2	0
margaritatus zone. 30 ft.	Dark-grey micaceous shales with layers of ironstone nodules. *Amaltheus margaritatus*, *A. gibbosa*, *A. lævis*, *Seguenziceras* spp., *Modiola scalprum*, *Nuculana Quenstedti*, *Ostrea* sp., *Gresslya* spp., *Plicatula spinosa*, *P. calvus*, *Eucyclus imbricatus*, *Cryptænia consobrina*	15	0

		ft.	in.
	Dark-grey micaceous shales with ferruginous concretions in beds and scattered. *Amaltheus* spp. (common). *Oistoceras* spp. and "*Androgynoceras*" spp. (decreasing towards the upper part). *Modiola subcancellata*, *Goniomya hybrida*, *Cucullea münsteri*, *Gresslya* spp., *Pecten* spp. . . .	15	0
Oistoceras sub-zone, *Liparoceras* sub-zone, and *latæcosta* sub-zone.	Dark-grey shales with reddish pyritic nodules, containing *Oistoceras figulinum*, *O. omissum*, *O. curvicornum*, "*Androgynoceras*" *capricornum* (Wright), *Amblycoceras crescens*, *Beaniceras* aff. *luridum*, *Lytoceras* sp., *Gresslya* spp., *Leda* (*Nuculana*) spp.	15	0
	Dark-grey clunchy clay with nodules and two shell beds, with capricorn ammonites, *Gresslya lunulata*, *Pecten* spp., *Pleuromya granata*, *Cucullea* sp., *Plicatula spinosa*	10	0
	Dark-grey shales with scattered nodules. Capricorn ammonites less common, *Androgynoceras* cf. "*striatum*", *Lytoceras* cf. *lineatus*. Wt. (non Schl.), very abundant. *Goniomya hybrida*, *Pecten æquivalvis*, *P. calvus*	10	0

(The bottom 20 feet was examined during the construction of a reservoir at the northern end of the pit in 1917 and is not now visible.)

The most remarkable feature of the fauna is the abundance and variety in the *Oistoceras* sub-zone of the capricorn ammonites, which with the "sphærocones" or "*striatum*"-like forms evolved from them pass into the lower part of the *margaritatus* zone. Thus species of *Amaltheus* and *Oistoceras* may be collected in the same bed up to within fifteen feet of the base of the *spinatum* zone. This feature does not seem to occur except around Lincoln, and possibly in North Lincolnshire, where Usshér[1] found capricorn ammonites only ten feet below the Marlstone rock bed (*spinatum* zone). "*Amm. striatum*" was recorded at Bracebridge by the Survey, but the ammonite usually known by this name occurs much lower in the sequence; the forms found at Lincoln previously included under that name are the sphærocone stages of *Amblycoceras*, *Oistoceras*, and *Androgynoceras*. It is hoped that these will be described shortly.

The section to be examined at the Albion Brickworks (formerly Handley's Pit) one mile north of the Lincoln Cathedral, shows a faunal succession which does not differ from that seen at Bracebridge, but there are some interesting differences in the lithology of the *spinatum* zone and the overlying Transition Bed.

SECTION AT THE ALBION BRICKWORKS.

		ft.	in.
tenuicostatum sub-zone.	Paper shales, weathered red and orange . . .	15	0
acutum sub-zone, 2ft. 6in.	Greenish shale with *Tiltoniceras* and *Dactylioceras athleticum*	1	6
	Ferruginous sandstone with Dactyloids (*D. athleticum*, *D.* cf. *tenuicostatum*, *D. semicelatum*, *Cæloceras* cf. *fonticulum*)	1	0

[1] A. E. Ussher, *Geology of North Lincolnshire, etc.* (Mem. Geol. Surv.), 1890, p. 49.

		ft.	in.
spinatum zone, 22 ft. 8 in.	Ironstone with phosphatic nodules. *Belemnites*, *Rhynchonella tetrahedra*, *Terebratula punctata*, *Cincta numismalis*, *Pleuromya costata*, *Pecten æquivalvis*, *P. lunularis*	1	0
	Light-grey shales with several thin phosphatic nodule beds . . . . . about	19	0
	Light-grey shales with *Amaltheus* sp.	1	0
	Ferruginous limestone with *Pecten æquivalvis* . .		10
	Several phosphatic nodule beds		10
margaritatus zone.	Shale . . . . . to base	30	0

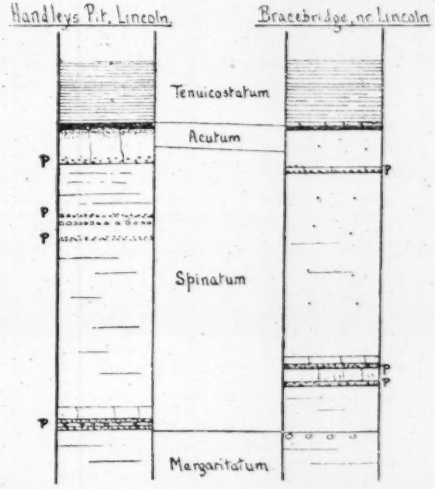


FIG. 3.—The Transition Bed and Middle Lias of Lincoln.
(P, level of phosphatic nodule beds.)

Comparing the *spinatum* zone in the above section with that at Bracebridge it is seen that the phosphatic nodule beds are not contemporaneous (Fig. 3), and cannot be used for correlation. J. H. Cooke,[1] after examining the section just described, concluded that the ferruginous limestone which is taken to be near the upper limit of the *margaritatus* zone was the Lincoln representative of the Marlstone of other localities. This was shown to be erroneous by the Rev. E. Nelson and Mr. H. Preston, who considered that the upper rock bed was the Marlstone equivalent. It must be noted, however, that only the lower part of this bed contains *spinatum* zone fossils; the upper part has numerous Dactyloids, a fact which was apparently overlooked by previous writers. Thus the Lincoln equivalent of the Marlstone ironstone of the south of the county is a light-grey shale with abundant phosphatic nodules at varying levels.

[1] J. H. Cooke, GEOL. MAG., Dec. IV, Vol. IV, p. 253, 1897.

The Transition Bed (*acutum* sub-zone), which has not previously been definitely proved except in Leicestershire, Northamptonshire, and Warwickshire, is well developed in the Lincoln district. The lithology of the lower part varies remarkably, consisting of clay at Bracebridge and of sand a few miles away, at the Albion works. The upper part, however, in both sections, consists of green shale. Dactyloids are common throughout (*Dactylioceras athleticum*, *D.* cf. *semicelatum*, *D.* cf. *tenuicostatum*), but the zonal fossil *T. acutum* appears to be confined to the green shale at the top. The Transition Bed of this district is thus different from that of the Midlands, where Dactyloids and *Tiltoniceras acutum* appear together in the lowest bed. Thus we must either conclude that only the upper portion of the Transition Bed of Lincoln is homotaxial with the Transition Bed of the Midlands, or else that *T. acutum* did not arrive in the Lincoln area until later. No indications of a break in sequence are to be found either at the top or bottom of the Transition Bed. If a break occurred, however, it would possibly be at the base of the green shale.

Immediately overlying the green shales of the Transition Bed at Bracebridge is an impersistent dark-grey limestone containing *Posidonomya bronni*, succeeded by paper shales with impressions of compressed ammonites. In places where the limestone is not present there is a more gradual transition between the shales and the junction is less easy to define.

In the cliff above the Albion Brick Pit the Upper Lias clays were formerly worked in Swan's Pit. This pit is now disused and the section cannot be fully studied, but is probably as follows:—

CLIFF ABOVE THE ALBION BRICK PIT.

		ft.	in.
	Oolitic limestone (Lincolnshire Limestone) . .	8	0
	Northampton Sands (ferruginous)	4	6
[Yeovilian and part of Whitbian deposits missing—non-sequence.]			
subcarinatum sub-zone. 50 ft.	Well-laminated shales, blue and black, with ferruginous nodules. Fossils rare. *Hildoceras bifrons*.	40	0
	Shell bed. *Trigonia pulchella*, *Nucula hammeri*, *Hildoceras*, *Dactylioceras*	1	4
	Shales and shell beds with *Dactylioceras*, *Frechiella subcarinata*	8	8
pseudoratum-falciferum sub-zones. 20 ft. 6 in.	Shell bed with *Lucina*	1	6
	Shale with shell beds and septaria containing *Harpoceras* aff. *mulgravium*, *Phylloceras* cf. *heterophyllum*, *Nucula*, *Belemnites subtenuis* about	19	0
exaratum sub-zone.	Shales, not now exposed . . . . about	15	0
tenuicostatum sub-zone.	Paper shales . . . . . about	15	0

In constructing the above section use has been made of those given by Messrs. W. D. Carr[1] and W. H. Dalton.[2]

The upper part of the Lias here is not very fossiliferous, but as no fossils of a higher horizon than *Hildoceras bifrons* have been found, it is probable that there is a non-sequence between the Lias and Oolites,

[1] W. D. Carr, GEOL. MAG., Dec. II, Vol. X, p. 164, 1883.
[2] W. H. Dalton, *Lincoln* (Mem. Geol. Surv.), 1881, p. 33.

the sub-zones from *fibulatum* upwards being absent. This supports the conclusion of W. H. Dalton.[1]

B. *Grantham.*

It is useful to compare the sections described above with those in the neighbourhood of Grantham. The junction with the overlying ironstone is exposed at the waterworks at Saltersford about one mile south of Grantham, where an extensive collection of fossils from the excavations was made by Mr. H. Preston, F.G.S., who generously placed his notes and specimens at my disposal. Much of the remainder of the Upper Lias is exposed in Rudd's Brick Yard, several hundred yards west of the railway station, while the Middle Lias may be seen in the brick-pits at Gonerby. The general section may thus be taken as follows :—

		ft.	in.
fibulatum sub-zone. ? 23 ft.	Micaceous shale, grey, iron-stained, unfossiliferous .	18	0
	Grey shales with *Pseudolioceras* cf. *lythense*, *Porpoceras vortex*, *P.* aff. *verticosum*, *Hildoceras bifrons*, *H. hildense*, *Phylloceras* cf. *heterophyllum*, *Peronoceras* cf. *attenuatum*. *Leda ovum* very abundant in pockets. (=Lower *Leda ovum* Beds of Northamptonshire)	5	0
subcarinatum sub-zone. 51 ft.	Grey shales with scattered nodules. *Hildoceras bifrons*, *Dactylioceras commune*, *D.* cf. *æquistriatum*, *D. hollandrei*, *Cœloceras crassum* . .	30	0
	Dark earthy limestone. *Hildoceras bifrons*, *Dactylioceras commune*, *Frechiella subcarinata* . .	1	0
	Grey shale with scattered nodules. Dactyloids abundant in nodules. In the lower part, *Harpoceras* aff. *mulgravium* occurs	20	0
pseudovatum-falciferum. sub-zone. 9 ft. 6 in.	Oolite Bed. Rubbly ferruginous limestone and clay with scattered Oolite grains. Many fossils. *Harpoceratoides ovatum*, Y. & B., in upper part. *Harpoceras* aff. *falcifer*, *H. mulgravium*, *H.* ? *strangwaysi*, *Dactylioceras gracile*, *D. acanthus*, *Cœloceras* aff. *fonticulum*, *Onustus* sp., *Nucula hammeri*		6
	Grey shale with nodules, *Harpoceras* aff. *falcifer*, *Dactylioceras* spp., *Cœloceras* aff. *fonticulum* .	9	0
exaratum sub-zone. 15 ft.	Grey shales with blue limestone nodules, containing well-preserved ammonites at all stages of growth. *H.* aff. *exaratum*, *Elegantuliceras elegantulum*, *Dactylioceras vermis*, *Inoceramus* . . .	15	0
tenuicostatum sub-zone. 15 ft.	Paper shales with flattened nodules; fish scales and insect remains	15	0
acutum sub-zone.	Unknown. Junction of Middle and Upper Lias not exposed		
spinatum zone. 35 ft.	Marlstone ironstone, with *Rhynchonella tetrahedra* and *Terebratula punctata* . . . about	20	0
	Micaceous clay with beds of rubbly ferruginous stone, yellow sandy layers containing many bivalves, and large ironstone septaria, *Pholadomya* sp., *Cucullea* sp., *Paltopleuroceras* spp.	15	0

[1] Loc. cit.

		ft.	in.
margaritatum zone. 55 ft. 6 in.	Grey micaceous shale with ferruginous limestone and thin bands of septaria. *Amaltheus margaritatus*, *Amaltheus levis*, *Cucullea münsteri*, *Pecten calvus*	25	0
	"Nodule Bed," a bed of ferruginous stone with small phosphatic nodules		6
	Dark-blue shale, with scattered septaria. *A. margaritatus*, *Seguenziceras algovianum*	30	0

The *margaritatus* zone at Grantham is much thicker than it is near Lincoln and the ammonites of the *Oistoceras* sub-zone do not pass into it. A curious feature of the *margaritatus* zone of Grantham is the presence of a bed of phosphatic nodules. It has been suggested that this bed is the equivalent of that seen near Lincoln,[1] but evidently its horizon is very different. No exposure of the Transition Bed has been examined in the Grantham neighbourhood, but it may be seen in the Caythorpe district, about eight miles to the north, where the following section was measured near the railway bridge, about a mile south of Caythorpe Church.

		ft.	in.
tenuicostatum sub-zone.	Paper shales with fish scales	12	0
? *acutum* sub-zone.	Ferruginous sand		4
spinatum zone.	Oolitic ironstone	2	0
	Blue-green ironstone weathering to reddish-yellow, fossils rare	12	0

South of Grantham the junction of the Middle and Upper Lias may again be seen near Harby, four hundred yards north-east of White Lodge.

		ft.	in.
tenuicostatum sub-zone.	Blue paper shales, *Dactylioceras tenuicostatum*, *D.* cf. *semicelatum*, *Pseudolioceras* sp. Fish scales	15	0
	Cream-coloured limestone with fish teeth and scales		1
? *acutum* sub-zone.	White limestone with many broken shells		2
spinatum zone.	Red ironstone, with abundant *Rhynchonella* and *Terebratula*	10	0

At neither of these places, however, have any ammonites been found in the beds which are taken to represent the *acutum* sub-zone. It will also be noticed that the Transition Bed thins out as it is followed southwards through the county; thus it is not in direct continuation with that of the Midlands. Probably there was a slight uplift over the greater part of the country after the hemera of *spinatum*, several shallow basins being formed, and during the hemera of *acutum* sediments only accumulated in these restricted areas, one of which was around Lincoln but only extended for a few miles to the south.

One of the most interesting fossils found in the Upper Lias of Grantham is one which Mr. S. S. Buckman has identified as *Harpoceratoides ovatum*, Y. & B., indicating the *pseudovatum* sub-zone, which had not previously been proved to exist outside

[1] H. B. Woodward, *Lias of England and Wales* (Mem. Geol. Surv.), 1893, p. 241.

Yorkshire.[1] The Oolite Bed, in the upper part of which this fossil was found, probably represents a period of slow deposition.[2] This period is similarly represented in Northamptonshire, where it lasted longer, during the deposition of the *subcarinatum* sub-zone, which is consequently much thinner than in Lincolnshire.[3]

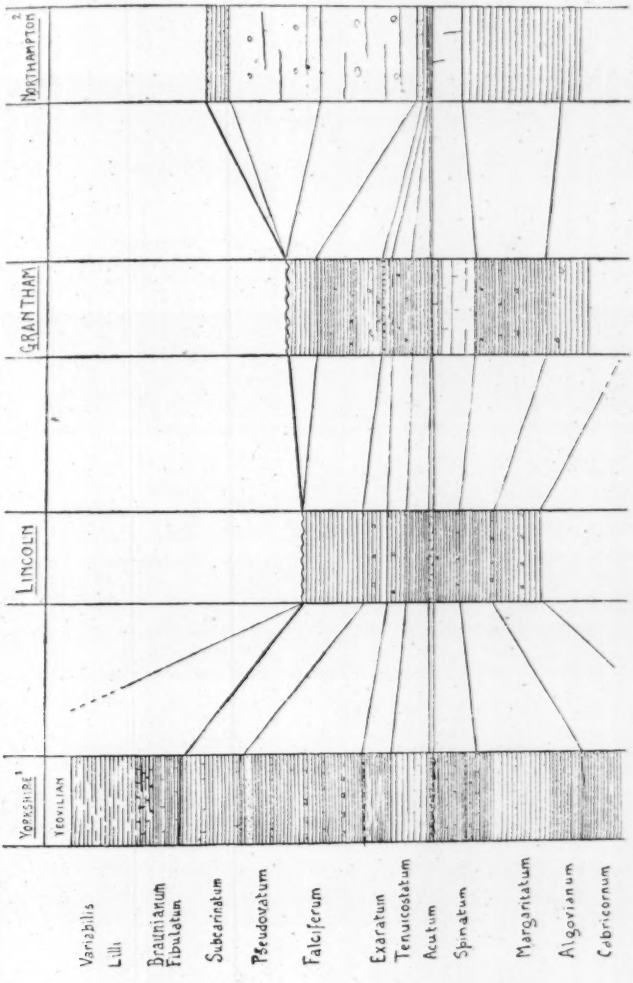


FIG. 4.—Middle and Upper Lias of Yorkshire, Lincolnshire, and Northamptonshire.
(Vertical scale, 1 inch equals 150 feet.)
[1] After S. S. Buckman, Whitby Memoir, 1915, p. 69. [2] After B. Thompson, Jubilee Vol., Geol. Assoc., 1910.

[1] S. S. Buckman, *Geology of Whitby, etc.* (Mem. Geol. Surv.), 1915, pp. 75, 102.
[2] H. Preston & A. E. Trueman, "Oolite Grains in the Upper Lias of Grantham": *Naturalist*, 1917, p. 217.
[3] B. Thompson, *Northamptonshire* (Jub. Vol. Geol. Assoc.), 1910, p. 462.

General Consideration of the Upper Lias. (Figs. 4 and 5.)

The variation in the thickness of the Upper Lias in Lincolnshire has resulted from two movements, viz.:

(1) A series of uplifts along an axis in South Yorkshire at intervals during the deposition of Lias and later rocks.

(2) The migration of the area of maximum deposition of the Upper Lias from north to south.

This latter movement was traced by Mr. S. S. Buckman,[1] who showed that the zones which are represented by thick deposits in Yorkshire, are only present as thin layers further south, while later zones not well developed in Yorkshire are very thick in the south. This migration of the area of maximum deposition may now be traced across Lincolnshire; thus the *tenuicostatum subcarinatum* sub-zones attain their maximum thickness in Yorkshire, and are fairly thick in Lincolnshire, but rapidly decrease in thickness towards Northamptonshire and the south. On the other hand, the *fibulatum* zone, which is only thinly represented in Yorkshire, shows increasing thicknesses at Grantham and Northampton. In this area it is interesting to notice that the places of minimum deposition in any zone are characterized by Oolitic beds. It is probable that during the deposition of the Upper Lias a shallow down fold passed gradually from Yorkshire southwards, its position determining the area of maximum deposit at any time.

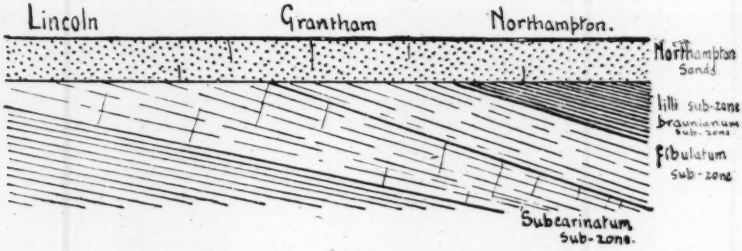


Fig. 5.—Diagram showing the relationship of the Northampton Sands and Upper Lias. (Not to scale.)

Accompanying this movement was one which probably commenced earlier, that is, an uplift or rather a series of uplifts along an axis in South Yorkshire. As a result of this the thickness of the Lias as a whole decreases as it is traced southwards across Yorkshire or northwards across Lincolnshire. The Upper Lias also decreases in thickness in the same way; in Northamptonshire it is about two hundred feet thick, at Grantham 115 feet, and at Lincoln only one hundred feet, diminishing still more rapidly further north until at Appleby[2] it is usually little more than fifty feet thick. The thinning, however, is probably not so regular as appears from these figures, for at Caythorpe, between Grantham and Lincoln, a boring showed the Upper Lias to be nearly two hundred feet thick,[3]

[1] S. S. Buckman, "Certain Jurassic (Lias-Oolite) Strata of South Dorset": Quart. Journ. Geol. Soc., vol. lxvi, p. 88, 1910.

[2] *Water-Supply of Lincolnshire* (Mem. Geol. Surv.), 1904, pp. 33–5.

[3] H. Preston, "On a New Boring at Caythorpe": Q.J.G.S., vol. lix, p. 29, 1903.

although judging from the fossils obtained, no higher sub-zones were present than usually occur in Lincolnshire. The change in thickness of the Upper Lias from Lincoln southwards, moreover, is not due to an increase in the thickness of the component zones, which vary in thickness as pointed out above, but is due to the greater extent of the non-sequence at the top of the Lias when traced northwards across Lincolnshire; thus, while the *fibulatum*, *braunianum*, and *lilli* sub-zones are present in Northamptonshire, of these only the *fibulatum* sub-zone is definitely represented at Grantham, and none of them are found at Lincoln. It appears, therefore, that uplift in South Yorkshire occurred at intervals, namely, during the deposition of Lower and Middle Lias, and towards the close of deposition of Upper Lias.

III.—Mountain Building.

By R. M. Deeley, M.Inst.C.E., V.P.G.S.

THE structure of mountain ranges has always been difficult to understand. They often show that peculiarly complicated disturbances of strata have occurred in the process of their formation. Mountain ranges in many stages of dissection are to be seen in various parts of the world; but the better knowledge which their study has furnished us with has not, at the moment, always assisted us in the better understanding of the problem of mountain building.

At the present time the compression theory may be said to be the one most generally accepted. It is thus described by James Geikie:[1] "Little progress could be made towards a satisfactory theory until the geological structure or architecture of individual mountain chains had been studied with precision. Many observations and descriptions of the folded rocks of the Alps and other regions had been recorded . . . but . . . geology could still present no clear conception of a mountain range as an organic unity . . . it was not until the appearance in 1843 of the well known essay by Professors W. B. and H. D. Rogers on the physical structure of the Appalacians, that geologists generally began to realize what is meant by the architecture of mountains of elevation. Thanks to the labours of these brilliant observers and their many successors, we are no longer in doubt as to the part played by compression in the formation of mountain ranges." That compression is the cause of the upheaval of mountain ranges, and the folded structure they present, James Geikie had no doubt, and he enforces his argument by pointing to the phenomena of cleavage, schistosity, etc., as the result of the same action.

To some, however, the amount of compression required to form a mountain range, not to mention the sharply marked anticlines and synclines of less elevated regions, seems greater than can be allowed. To again quote James Geikie,[2] "While overfolding and wholesale horizontal displacements are the most characteristic features of Alpine architecture, it must not be forgotten that compression

[1] *Mountains, their Origin, Growth, and Decay*, 1913, p. 66.
[2] Ibid., p. 130.

resulted only in the bulging up or general elevation of the great central massifs, and in diminishing the width of the entire Alpine area. Many years ago Professor Heim was of opinion that if all the Alpine folds were smoothed out and the strata regained their original position, they would necessarily extend over a much wider area; the two points Zürich and Como, for example, would be further apart than they are at present by some 120 to 150 kilometres. But this estimate he thinks is now much under the mark; according to him, the Alpine area before compression took place was a flat land measuring probably 600 to 1,200 kilometres across. Instead of this broad low-lying tract, we have now a lofty mountain chain averaging no more than 150 kilometres in width." He accounts for the compression by adopting the theory that "The movements referred to are doubtless due to the wrinkling of the earth's crust over the slowly cooling and contracting material".

The above quotations have been made for the purpose of showing what may be considered to be the attitude of very many geologists at the present day. However, the theories he advocates he did not originate, but they certainly appeared to him to be sufficiently well established to admit of their being placed before the public as sound.

Many physicists who have carefully studied this theory of compression by cooling are quite satisfied that it is not capable of accounting for the amount of compression required. O. Fisher, for example, maintains that secular contraction of a solid globe through mere cooling will not account for the observed phenomena. The idea is that the already cooled surface of the earth was thrown into folds as the hotter interior cooled. We must assume, for instance, that during the formation of the Alps the compression may have amounted to 1,200 – 150 kilometres, or 1,050 kilometres. To effect this, even if the whole of the crumpling were concentrated in the Swiss Alpine region, the earth must have decreased in diameter by about 334 kilometres. Indeed, the contraction that is required in the diameter of the earth is very much greater than can possibly be allowed.

Thrust planes have also been regarded as proof of compression.[1] J. Geikie remarks: "But notable as these rock-movements are, they cannot compare in extent to the similar translations which have been recognized in Scandinavia, where in one particular case a massive sheet, many thousand feet thick, is believed by some geologists to have been driven from west to east, for a distance apparently of 80 miles or thereabouts." It is unfortunate that these faults should have been called "thrust planes". It would be impossible to *thrust* a sheet of rock over the surface beneath if the proportions of thickness to distance were anything like those mentioned. A force applied to one end of such a rock sheet would merely buckle it up for a short distance. "Gliding plane" would be better than "thrust plane" as a name for such phenomena.

In view of the considerations that have been mentioned, it would be well to consider whether the folding, etc., that is so often exhibited in mountain chains may not be the result of other agencies.

[1] Ibid., p. 173.

Some experiments recently made by the author of this paper,[1] showed that when a heavy viscous layer of sealing-wax loaded with sand rested upon a layer of pitch, the heavy wax sank into the lighter layer below, in such a manner as to simulate the effects of compression. This point was noticed by Mr. G. W. Lamplugh, who called my attention to it, and he inquired whether the same conditions could be applied to the folding of mountain chains. If such were the case the folding would result in local tension, not general compression.

The experiment above referred to was made for the purpose of showing that when a heavy bed of sandy gravel, or clay with stones, rests upon a soft clay or brickearth, if the two deposits were brought into a viscous condition after frost, then the heavy overlying bed would settle into the lighter bed below in a manner which would produce a structure very closely resembling the "trail and underplight" of Spurrell.

That the crust of the earth is flexible, and that it, therefore, can sink and rise, as denudation and deposition take place, is now generally conceded. In the case of the Gangetic trough Oldham,[2] though not considering that the trough owes its origin to the weight of the alluvium, remarks: "But though the weight of the sediment cannot have been the originating cause of the depression of the Gangetic trough, it may have had considerable influence in determining the magnitude of its dimensions, for if there had been some other cause capable of forcing down the level of the crust to a given depth before the resistance to further movement became equal to the force, then the addition of a load of alluvium would enable the same force to lower the level to a greater extent than if the hollow had been left empty or only filled with water. The amount of this extra depression would depend on the balance between the force and the resistance; if both remained appreciably constant, within the limits of the movement involved, the weight of the alluvium would enable this to be carried about five times further than would otherwise be the case, so that the Gangetic trough, taken as 15,000 feet deep, would only have a depth of about 3,000 feet had it not been filled with alluvium as fast as it was formed."

The above reasoning is based upon the fact that wherever mountains occur it has been found that the crust beneath them is of low density and that the mountains float upon this lighter material. Similarly, beneath the deep seas the crust is of high density and the land level is caused to sink to great depths. As changes in the level of the land have been numerous, and of great magnitude during geological time, it is clear that changes in the density of the lower portions of the earth's crust are continually but slowly taking place. As long as such areas of high or low density persist there will continue to be mountains or deep seas. Denudation alone cannot reduce a mountain

[1] R. M. Deeley, "Trail and Underplight": GEOL. MAG., Dec. VI, Vol. III, pp. 2–5, 1916.

[2] "The Structure of the Himalayas": Geol. Survey of India, vol. xlii, pt. ii, p. 122.

range; for as long as the rocks below are of low density the mountain mass will rise as fast as material is removed by denuding influences.

The cause of the variations in the density of the deep-seated portions of the earth's crust is as yet uncertain; but we are entitled to regard the crust as floating upon a liquid stratum of great viscosity, or a very plastic solid stratum.

It may not be out of place to explain what is here meant by plasticity and viscosity.

Although it is certain that our present knowledge of the properties of fluids and solids, from the physical point of view, is by no means complete, it will not be out of place to consider some of the very complex phenomena they exhibit, and which have a bearing upon geological problems. The subject is, indeed, one of very great importance to the engineer and physicist, for to the former the physical properties of solids have to be considered as far as they affect the stability of all kinds of structures, whilst in the case of the latter they have to be borne in mind when dealing with the question of the stability of mountain ranges, etc.

One very frequently hears semifluids spoken of, and there are many who are of opinion that there is a regular transition of the solid into the liquid state, or that there are a large number of substances which can be arranged in such an order that they show a transition from the solid to the liquid state. The idea that liquidity is only a matter of degree was well expressed by Tyndall,[1] who writes: "What was the physical condition of the rock when it was thus bent and folded like a pliant mass? Was it necessarily softer than it is at present? I do not think so. The shock which would crush a railway carriage, if communicated at once, is harmless when distributed over the interval necessary for the pushing in of the buffer. By suddenly stopping a cock from which water flows you may burst the conveyance pipe, while a slow turning on of the cock keeps all safe." All this is more plausible than sound. He then goes on: "Might not a solid rock by ages of pressure be folded as above? It is a physical axiom that no body is perfectly hard, none perfectly soft, none perfectly elastic. The hardest body subjected to pressure yields, however little, and the same body when the pressure is removed *cannot return* to its original form. If it did not yield in the slightest degree it would be perfectly hard; if it could completely return to its original shape it would be perfectly elastic."

"Let a pound weight be placed upon a cube of granite; the cube is flattened, though in an infinitesimal degree. Let the weight be removed, the cube remains a little flattened; it cannot quite return to its primitive condition. Let us call the cube thus flattened No. 1. Starting with No. 1 as a new mass, let the pound weight be laid upon it; the mass yields, and on removing the weight it cannot return to the dimensions of No. 1; we have a more flattened mass, No. 2. Proceeding in this manner, it is manifest that by a repetition of the process we should produce a series of masses, each succeeding one more flattened than the former. This appears to be a necessary consequence of the physical axiom referred to above.

[1] *Glaciers of the Alps*, 1860, p. 9.

"Now, if instead of removing and replacing the weight in the manner supposed, we cause it to rest continuously on the cube, the flattening, which above was intermittent, will be continuous; no matter how hard the cube may be, there will be a gradual yielding of its mass under pressure."

Since the above was written a great deal of additional information has been obtained experimentally; but very few attempts have been made to put this in a form which would be useful to the geologist, or even to the engineer who has not made a special study of the subject; and one may say with truth that although Tyndall's statement now seems very far from being a complete or even correct one, many modern writers seem to base their geological theories upon some such theory of the solid and liquid states.

From the scientific point of view there is every reason to believe that the solid and liquid conditions of matter must be regarded as quite distinct physically, and that when the one state passes into the other the change is abrupt.

In the case of a liquid, if it be placed in a hollow cup-shaped vessel it will be found that the upper surface is a perfectly level one. Water, for example, after a few oscillations, settles down quickly. A thick lubricating oil does so more slowly; but pitch may take weeks or even years to reach the perfectly horizontal position. There is no question but that all liquids, under such conditions, flow until their upper surfaces are quite horizontal, and in this respect they are all true liquids but differ in viscosity. In every portion of the mass the stresses eventually become equal and opposite.

If small boats be placed on these liquids, in the case of oil and water they will quickly sink until they have displaced their weight of oil or water. In the case of the pitch, a similar boat, when first placed on the surface, will rest there, but it will slowly sink into the pitch until it also floats and displaces exactly its own weight of pitch. Oil, water, and pitch are all perfect liquids, but pitch is more viscous than oil, and oil is more viscous than water. At the same temperature and pressure the fluidity (viscosity) is always the same in the case of liquids possessing definite chemical compositions, and may be expressed in terms of some particular unit such as Poise, which is a C.G.S. scale.

A solid may be either hard or soft, but however soft it may be it is not a liquid. Thus, if we had a very large vessel partly full of soft clay (a material much softer than pitch), its upper surface would *never* become quite flat. If a heavy boat were placed upon the soft clay the boat would sink some distance into it, but it would *never* sink until it displaced an equal weight of clay. Indeed, it would sink to a certain distance into the clay quite rapidly, and would then come practically to a standstill. However, it might go on continuously sinking slowly and yet never displace its weight of clay. This may be illustrated in the following way: Imagine that the rate at which it sinks gets slower and slower. Take it that in the first hour it sinks half a yard. In the next hour it sinks one-quarter of a yard, in the next one-eighth of a yard, and so on. At this rate it will always be sinking, but will never sink more than one yard. Tyndall's

cube would deform in some such way as this, and the deformation would *never* become appreciable.

However, if a soft solid have too great a weight placed upon it, it will yield continuously much as will a liquid. In extruding lead through a hole in a cylinder no movement takes place until a certain pressure is reached; the lead then flows out through the hole and flows faster as the pressure is increased.

Now the upper portion of the earth's surface is composed of rocks varying in hardness. Buildings may be erected upon it which will be permanently stable, provided the load on their foundations is not too great. The load per square foot that may with safety be placed upon each kind of rock varies considerably, and it is the engineer's endeavour to find out what is the smallest area and depth of foundation that will ensure stability in each case, so as to keep the cost of the building as low as possible.

The load-carrying capacity of any kind of rock varies much according to surrounding conditions. Dry clay will carry more than wet clay. On this account the water escaping from a burst water-pipe may so soften the clay or marl upon which a building rests that the foundations give way. Vibrations caused by heavy vehicles have the same effect. Railway bridges and retaining walls have to be made much stronger, for the same loads, than have road bridges and walls. No doubt the foundations of St. Paul's Cathedral were, in most instances, amply sufficient under the conditions existing when Wren built it, but the vibrations resulting from the heavy road and rail traffic of our times, and the effects upon the local drainage produced by sewers, etc., have much interfered with their stability.

The nature of the resistance to stress offered by the materials forming the earth's crust is in some cases of a liquid and in others of a plastic description. The liquids, whether water or molten rock, settle down with their upper surface layers practically horizontal; but owing to their varying density and the plastic resistance they offer to flow, the solid rocks stand at various levels. We thus have large raised areas floating upon "roots" of light material and depressed areas over roots of heavy material, the whole floating upon a plastic or liquid substratum. It has been suggested that this substratum rests upon harder material, and it has been called the asthenosphere. But the raised areas are not necessarily quite stable. The materials of which they are built up are being denuded and carried to lower levels, with the result that the area rises to restore the balance, and the areas over which deposition takes place sink for the same reason.

The flexing of the earth's crust by the moon results in "earth tides", and these, together with earthquake shocks, have the same effect upon the stability of mountain masses as have the vibrations produced by heavy traffic upon the foundations of St. Paul's Cathedral. Elevated areas consequently tend to flow and spread outwards over the surrounding lower lands, or to slide under the action of gravity bodily into depressions. Such sheets of rock are not pushed along by pressure applied at one end; they slide bodily down

a slope under the action of gravity, every yard of the mass furnishing its own propulsive force.

How the dense "roots" of depressed areas and the lighter "roots" of elevated areas arise, it is not my intention to discuss. That such roots exist a perusal of the paper by R. D. Oldham already referred to will demonstrate.

Rain, rivers, etc., attack the elevated areas, cutting out river valleys of varying width. The character of the resulting scenery depends upon the nature and hardness of the rocks. The depth and width of the valleys resulting from denudation must bear a close relationship to the forces required to make the rocks flow. When the rocks are soft and erosion results in the production of deep valleys, then the valley bottoms rise, the sides close in, and various irregularities in the bedding planes result. In this way anticlines and synclines are very frequently formed *without* lateral pressure. Such movements are greatly assisted by temperatures.

The crust of the earth grows warmer and warmer as the depth increases. This gradient of temperature in the crust is about 1° F. for every 70 feet of descent. At great depths the rocks are consequently very hot. Now a solid almost always becomes softer and softer as the temperature is raised, and the force which will cause it to flow becomes smaller and smaller. If the temperature were raised so high that the force which would produce continuous flow fell to almost zero, then the solid would have been abruptly turned into a liquid, and flow would result however small the force might be.

When a plastic substance is distorted microscopic examination shows that it has resulted from the formation of many distinct shear planes. On the other hand, the distortion of a viscous substance is caused by shear between planes whose thicknesses are of molecular dimensions.

A piece of granite overloaded would break into small fragments. It would not flow like soft clay. However, if the granite were surrounded by some substance under very great pressure, then the particles of rock would be so firmly held together that it would not fracture if deformed; but would change its shape without breaking. It thus comes about that although hard rocks are fractured by earth movements near the earth's surface, they remain massive at great depths although they suffer distortion. This ability of rocks at great depths to suffer distortion without fracture is, of course, much assisted by the high temperature prevailing there.

The idea that the surface rocks are floating in very many places upon a fluid stratum can be shown to be probable by many phenomena. During Tertiary times, over an area of some 200,000 square miles of what is now Idaho, Oregon, and Washington, fluid basic lavas welled up more or less steadily through great fissures, and covered the whole country with sheets of lava aggregating in places 2,000 feet or more in thickness. In India a like area was covered to a depth of from 4,000 to 6,000 feet, while over the Lake Superior basin and some of the surrounding areas the thickness reached by more ancient lava floods was from 15,000 to 25,000 feet. There are amongst these lavas very few beds of ash or cinders, so

that the eruption or welling up of these enormous volumes of lava was not of a violent character. There are many cases also where huge blocks of country, bounded by faults, have subsided, and the liquid magma below has issued along the fault lines.

We must, therefore, take it that large areas of the earth's surface have been, and probably now are, really resting upon a substratum of liquid or nearly liquid rock, and that in many cases the cooler and heavier surface rocks have subsided bodily, the liquid rising through great fissures and spreading over them as they sink. Here there are no signs of compression; rather has the crust been stretched to form the fissures through which the lava welled up.

No ordinary amount of compression could give rise to a mountain range; for as the rocks thickened locally under the compressive forces, their weight would cause them to sink, and depression might result rather than elevation. It has been suggested that the heating up is caused by compression. However, in the case of North America, where the vast quantities of basic lava welled up, the rocks are generally horizontal and show no signs of compression. All that can be made out is that mountain chains seem to have risen in areas which have been ones of active recent deposition, and do not appear to have formed in areas covered by rocks of great age. All our great modern mountain ranges were raised in Tertiary times over areas of recent deposition.

It is probable that our anticlines and synclines are generally the result of the irregular sinking of the earth's surface where it rests upon fluid or very plastic magmas. The syncline of the Thames Valley, for example, would seem to have varied from time to time, sometimes becoming more pronounced and then flattening out again.

The view that rocks of varying density resting upon a liquid substratum may produce synclines and anticlines has already been suggested by Coleman.[1] He says: "Some years ago I ventured another explanation. Granite is specifically lighter than most of the greenstones and schists of the Kewatin; and molten granite, even if not at a very high temperature, is lighter than the relatively cold rocks above it. If the rocks above were unequally struck, so that some areas were less burdened than others, it is conceivable that these differences in gravity might cause the granite to creep slowly up beneath the parts with lightest loads, whilst overlying rocks sagged into synclines in the heavily loaded parts."

"Whatever the cause, these batholiths enclosed by meshes of schist are the most constant feature of the Canadian Archæan, though in many places erosion has cut so deeply that the meshes have all but disappeared, leaving only straight or curving bands of hornblende schists enclosed in Laurentian gneiss."

Here we appear to have a mountain mass so deeply dissected by denudation that the cause of the existence of the anticlines and synclines which no doubt characterized the ranges is disclosed. The folds were not formed by lateral pressure, but by the stretching of the beds of rock as some portions settled down and others rose.

[1] Presidential Address, Brit. Ass. Rep., 1910, p. 54.

However, the bending of the rock stratum, although resulting in a general stretching, would also produce local compression. That a mountain range may be resting upon a liquid or very plastic base, as would appear to have been the case with the old mountain range the "roots" of which are now the Canadian shield, leads to some important consequences.

My chief endeavour has been to show that there are other ways of accounting for anticlines and synclines than by compression. To further illustrate the suggestion some remarks will be made concerning the history of the Swiss Alps.

The structure of the Swiss Alps was for many years an enigma; but there seems every reason to believe that the broad outlines of their architecture are now known.

At the base we have crystalline gneisses, schists, and granites. They form the lofty massifs of Mont Blanc, the Aiguilles Ronglies, the Bernese and Gothard Alps, etc. They once formed a highly worn or much denuded surface, upon which the newer rocks were deposited. The older rocks are chiefly crystalline masses and some Carboniferous strata, while the overlying bedded series range in age from Permian and Triassic down to early Cainozoic. These sediments filled up the valleys and submerged the mountains of the old land. The area over which they were deposited was a subsiding one. We are told that after the deposition of these sediments the sea bottom was raised and a low flat undulating land area was formed; and that great rock-sheets from the north and south were then thrust up gentle inclines over this land. The chief of these sheets are the Helvetian, Lepontine, East-Alpine, and South-Alpine. That these sheets could have been thrust up and over each other and over a rising land seems quite impossible. That they are there, and have travelled great distances, is certain; but the conditions under which they have travelled require further elucidation.

It may be that the sea in which these early sediments were deposited became very deep, and that the rock-sheets slowly slid into this deep sea one after the other; for in most instances the upper sheets are formed of older rocks than the lower ones. The covering of the sea bed by cold rock-sheets instead of water would deepen the sea, whilst the removal from the shallow water or land of the cold rock-sheets would be replaced by rising warmer rock. This would increase the gradient and result in further slides.

The whole mass was then raised and folded. It is very doubtful if this folding was the result of pressure: rather may it have been due to the differential vertical earth movements resulting from denudation. During the rising of the Alps great deposits were formed along the margins of the mountains. It is a peculiar fact that some of the rock folds have moved outwards and been thrown over these deposits. Indeed, it may be that overfolds are not due to thrust; but are due to the flow of the elevated rocks near the margins of the mountains towards or even over the surrounding low lands.

It is rather a rash thing perhaps to suggest that compression has not been a prime factor in earth movements; but the difficulties that can be urged against the idea are so very great, that it cannot be

considered more than a working hypothesis until the physical difficulties are met. If it can be shown that compression is not required, and that the phenomena of folded mountain chains can be otherwise explained, a distinct advance would be made in dynamical geology.

IV.—Datum-lines in the English Keuper.

By R. L. Sherlock, D.Sc., A.R.C.Sc., F.G.S.

In the almost complete absence of fossils in the British Keuper there has been a lack of datum-lines in that formation by which we may compare the horizons of different sections. Yet in such a thick and widely spread deposit it is very desirable to have subdivisions enabling us to give the particular part of the Keuper to which a section belongs. In deposits such as the New Red formations too great stress has been laid on lithology, inevitable perhaps in the scarcity of fossils, but a source of grave errors in correlation. For example, Mr. L. J. Wills[1] thinks that fossils found in the Keuper of Warwick have affinity, not with the Keuper, but with the Muschelkalk of Germany. Again, there are strata in the Permo-Bunter of Nottinghamshire[2] which might be mistaken for Keuper Waterstones, if only lithology was considered. Over small areas a band of sandstone with some peculiarities may be used as a datum-line, as in the Arden district of Warwickshire[3] and in Nottinghamshire,[4] but these are of local value only.

Recently Mr. Bernard Smith and myself have had occasion to visit all places where gypsum is worked, or likely to be workable, throughout England, and it appears that the workable deposits of gypsum within the Keuper occur at definite horizons. The economic results have been published in a recent memoir,[5] but I wish here to show that they give us two definite horizons, the upper one found at intervals between North Yorkshire and Somerset and the other over parts of three Midland counties. Using these datum-lines, I propose to show that they help us to state the nature of the Keuper–Rhætic junction and to determine whether or not the Tea-green Marls occur at a definite horizon.

1. *The Upper Horizon.*—Four beds of gypsum occur in a definite order in the quarries and mines situated between Beacon Hill (Newark) and Orston, to the south-west, a distance of 9½ miles. In the figure sections are given of the strata found at Newark, Hawton, Bowbridge, and Orston. Those at Newark, Bowbridge, and Orston

[1] "On the Fossiliferous Lower Keuper Rocks of Worcestershire": Proc. Geol. Assoc., vol. xxi, p. 268, 1910.

[2] R. L. Sherlock, "The Relationship of the Permian to the Trias in Nottinghamshire": Quart. Journ. Geol. Soc., vol. lxvii, p. 82, 1911.

[3] C. A. Matley, "The Upper Keuper (or Arden) Sandstone Group and Associated Rocks of Warwickshire": Quart. Journ. Geol. Soc., vol. lxviii, pp. 252–80, 1912.

[4] B. Smith, "The Upper Keuper Sandstones of East Nottinghamshire": Geol. Mag., 1910, pp. 302–11.

[5] R. L. Sherlock & B. Smith, *Special Reports on the Mineral Resources of Great Britain* (Mem. Geol. Surv.), vol. iii, "Gypsum and Anhydrite," 1915.

have already been published.[1] The two latter mines and quarries belong to The Vale of Belvoir and Newark Plaster Company, the others to Messrs. Cofferata & Co., and my thanks are due to these two firms for the kindness with which they have allowed me to visit the sections, and for information. The distance from Beacon Hill, Newark, to Hawton is about 2 miles; Hawton and Bowbridge are only separated by some 350 yards, Bowbridge lies slightly to the east of Hawton, and in consequence of the easterly dip higher beds are visible at Bowbridge than at Hawton. From Bowbridge to Orston is about 7 miles. The Orston mine was at the time (1915) disused and the details of the section were given by the proprietor. Except at Orston the seams of gypsum are visible throughout the extensive sections (the Hawton quarry is about 700 yards long), and occur in the same order and at approximately the same distance apart, and there is no doubt that they are definitely bedded deposits. Additional evidence of this is furnished by the fact that some of the accompanying beds can be correlated in different sections. Thus, the "Riders" (see Sections, p. 122), a nodular band of gypsum resembling a line of flints in chalk, occurs between the Top and Middle White Rocks, at Newark, at Hawton, and at Bowbridge; while the "Bastard", a 3 ft. band of mixed green marl and gypsum, occurs 7 feet above the Top White Rock at the same three localities.

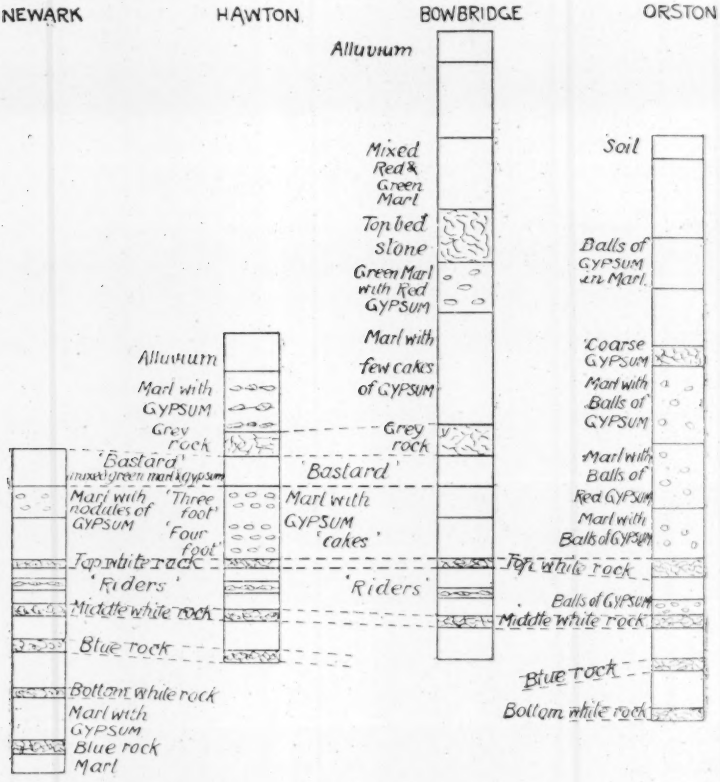
At Beacon Hill, Newark, some 66½ feet of strata intervene between the Top White Rock and the base of the Rhætic beds.[1] At Bowbridge there are 45 feet of strata exposed above the rock, and, in addition, a certain amount crops out under alluvium between the section and the Rhætic escarpment. At the constant dip prevalent over the district there is room for about 20 feet of strata in this gap, giving approximately 65 feet of strata up to the Rhætic base, or practically the same as at Newark, 2 miles away. At Orston there is recorded 39 feet of strata above the Top White Rock. Unfortunately the section cannot now be seen, and the exact thickness of strata cropping out between it and the Rhætic base, cut through in the railway about 20 yards away, cannot be measured exactly. It would appear that the total thickness of strata between the Top White Rock and the Rhætic is a few feet less at Orston than at Newark.

This evidence shows that between Newark and Orston the Rhætic is separated from the Top White Rock by a belt of strata of practically constant thickness. In the absence of complete sections it cannot be said that the thickness of the intervening strata is absolutely constant, but it can be said that throughout the distance of 9½ miles the variation is not more than a few feet and may be quite absent, and that over a distance of 2 miles there is no variation whatever. Exact correspondence in thickness of the marl beds in any two sections is not to be expected, as we may see from the sections figured, and any small differences in the thicknesses of the intermediate strata are more likely to be due to variation (and cancel themselves out) than to an unconformity, however slight, of the

[1] A. J. Jukes-Browne, *Geology of the South-West part of Lincolnshire* (Mem. Geol. Surv.), 1885, p. 18.

Rhætic. Hence we may conclude that in this district the Rhætic is strictly conformable to the Keuper.

Away from the Newark–Orston district we cannot trace the individual beds of gypsum. We do find, however, that a belt of strata containing beds of gypsum occurs at approximately a constant distance below the Rhætic beds at numerous places between Middlesbrough and Somerset. The gypsiferous belt is of varying thickness, being better developed in some places than in others, and we cannot



Sections in the Newark District of Nottinghamshire.
Scale : 1 inch represents 18 feet.

pick out a particular seam as a datum-line over a large area. But the belt as a whole may be so treated, if its approximate middle be taken. North of Newark the belt becomes more poorly developed, but it has been worked in the past at Laughterton, near Gainsborough; at Winton, Stank Grange, Hallikeld, and Little Sessay, near Northallerton; and at Eston, near Middlesbrough. Proceeding in the opposite direction, it is worked at Cropwell Bishop, Notts. In

Leicestershire the gypsiferous belt is seen at Thurmaston Brickyard and at Gipsy Lane Brickyard,[1] Leicester; but between Cropwell Bishop and Tutbury in Staffordshire the lower horizon of gypsum (to be mentioned later on) is economically the more important one. Near Penarth, in Glamorgan, near Yate, in Gloucestershire, and near Watchet, in Somerset, the upper horizon is being, or has been, worked.

It is remarkable that although on the west side of Watchet gypsum is abundant enough to be quarried, at St. Audries,[2] on the east side of Watchet, it is quite absent. But a band of indurated marl, 4 to 6 inches thick, occurs containing celestine, at a depth of 69 feet below the base of the Rhætic, i.e. at the horizon of the gypsum. At Yate, in Gloucestershire, the celestine deposits occur at the same horizon as the gypsum, but only in one place have the two minerals been found together. We may therefore infer that at St. Audries the absence of gypsum is due to the presence of celestine at the same horizon.

2. *The lower horizon* of gypsum is worked extensively in the Gotham district of Nottinghamshire and in East Staffordshire. A bed of gypsum, usually from 7 to 11 feet in thickness, is worked at Gotham, East Leake, Barton, Thrumpton, and Kingston-upon-Soar, all in Nottinghamshire, and the gypsum of Chellaston, Derbyshire, probably belongs to this horizon. In Staffordshire the bed is from 8 to 15 feet in thickness, and is worked in the parishes of Hanbury and Draycott. The bed is characterized by a ball-like structure on a large scale, the thicker parts of the seam representing more or less distinctly the sphæroids, and the thinner parts the intervals between them. In thickness and sphæroidal structure the bed is fairly well marked off from other beds of gypsum in the Keuper.

At East Leake the gypsum is said to occur about 150 feet below the Tea-green Marls. This is but a rough estimate, and the thickness of Tea-green Marls is not stated. The Tea-green Marls vary a good deal in thickness, but at Newark, where they are best seen, there is about 18 feet of them. This would give roughly 168 feet of strata between the gypsum and the Rhætic beds. At Glebe Mine, Gotham, the details of a ventilating shaft have been preserved,[3] and show a thickness of 160 feet between the gypsum and the Rhætic beds. At a depth of 86 feet below the Rhætic a thick bed of gypsum was found, and this is probably part of the upper belt. At Fauld, near Tutbury, Staffordshire, the gypsum is thought to be about 145 feet below the top of the Keuper Marl. The discrepancy between the depth here and at Gotham may be due to various causes, but a likely one is that, as Rhætic beds were not separated from Lias when the district was mapped, about 1852, it is probable that the Tea-green Marls have been put with them in the Lias, in accordance with the then current idea that the green marls were part of the Rhætic. If

[1] For full section see T. O. Bosworth, *The Keuper Marls around Charnwood*, Leicester, 1913, p. 117.

[2] Vertical sections, Geol. Surv., Sheet 47, No. 6.

[3] *Special Reports on the Mineral Sources of Great Britain* (Mem. Geol. Surv.), vol. iii, p. 26, 1915.

so, the depth of the gypsum below the Rhætic might be much the same as at Gotham. In Warwickshire gypsum occurs at Spernall Park, 7½ miles north-west of Stratford-upon-Avon, at about 150 to 160 feet below the Rhætic beds, but not in workable quantities. Owing to the scarcity of measured sections we cannot be certain that this second horizon occurs at a constant depth below the top of the Keuper—it is only probable.

The question of the mode of origin of gypsum is a big one and cannot be gone into here. It suffices that the gypsiferous deposits we are dealing with are clearly, in the main, primary strata, although secondary gypsum is also present, and the deposits represent some special condition, occurring at a definite period over a wide area and therefore of chronological value.

The occurrence of these two belts of gypsiferous strata at approximately constant depths below the Rhætic beds points strongly to the conformability of the Rhætic to the Keuper. The sharp line of demarcation between them is therefore no more than the result of the waves of the open sea entering the Caspian-like sea in which the Keuper was deposited and washing up the Keuper mud.

The highest beds of the Keuper are the Tea-green Marls, at one time considered to be part of the Rhætic beds. If the Rhætic were unconformable to the Keuper it would follow that the Tea-green Marls occurred at varying positions in the Keuper Series, and it would be highly probable that the green colour is the result of alteration of red beds by secondary changes. But if, as the evidence given above seems to show, the Rhætic is conformable to the Keuper, then the Tea-green Marls everywhere occur at about the same horizon, so far as the upper boundary is concerned, and there is a probability that their colour is original. The green strata, however, vary greatly in thickness, for instance at Colston Bassett, Nottinghamshire,[1] they are only about 15 feet thick, whereas near Watchet[2] they are 115 feet in thickness. Also the base is often indefinite, sometimes dying out downwards raggedly, sometimes ending in alternate beds of green and red marl. Hence, the top being fixed, the base must occur at somewhat different horizons in different places.

One result of the wide variations in thickness of the Tea-green Marls is that the higher gypsum horizon is sometimes below it, in red strata, as in Nottinghamshire, and sometimes well within the green beds, as at Watchet. It appears that the conditions of formation of green marl were neither inimical nor helpful to the formation of gypsum.

The green strata seem to indicate the coming of the open-sea conditions. The occasional presence of fossils such as *Ostrea bristoei*, Richardson, recorded by Mr. L. Richardson,[3] indicates a change in

[1] B. Smith in *Geology of the Melton Mowbray District and South-East Nottinghamshire* (Mem. Geol. Surv.), 1909, p. 16.

[2] L. Richardson, "The Rhætic and Contiguous Deposits of West, Mid, and part of East Somerset": Quart. Journ. Geol. Soc., vol. lxvii, pp. 19–20, 1911.

[3] L. Richardson, "The Rhætic and Contiguous Deposits of Glamorganshire": Quart. Journ. Geol. Soc., vol. lxi, p. 399, 1905.

the water, perhaps due to the washing in at spring-tides of waves from the open sea, now almost ready to break into the landlocked area in which the Keuper Marl was formed. It is interesting to note that, north of Nottingham, Tea-green strata also occur, at the bottom of the Keuper, unconformable to the Bunter below, and perhaps representing the last traces of brackish water before the area was finally cut off from the open sea.

V.—A Note on Isostasy.

By A. Morley Davies, A.R.C.S., D.Sc., F.G.S., Imperial College of Science and Technology.

THERE is a regrettable tendency to looseness of thought among geologists on the subject of isostasy. I give no quotations in support of this assertion, firstly because, being always in the form of casual allusions to the principle, they would require long hunting down; and secondly because, if given, they would fasten upon a few individual geologists a criticism which should be more general. The usual form in which the looseness of thought shows itself is in explanations of shallow-water deposits of thickness greater than their depth of accumulation. We are frequently told that such thick deposits result from local subsidence due to the loading of the sea-floor by the great weight of sediment, and reference is made to the principle of isostasy as justifying this explanation.

The principle of isostasy is that the distribution of mass in a heterogeneous earth tends to be so adjusted that variations of the surface from the theoretical ellipsoid of rotation are compensated by differences of density in the deeper parts of the underlying crust. The continents are supported on a mass of less density, the oceans on a mass of greater density; and similarly for the mountain-chains and ocean-troughs in relation to the average of the continents and oceans respectively.

This compensation of excess of matter at the surface by defect of density below and of defect at the surface by excess of density below is termed isostatic compensation, and the adjustment of the earth's crust towards a condition of isostatic equilibrium caused by gravitative stress is termed isostatic adjustment. Compensation is supposed to be complete within a comparatively shallow depth (122 kilometres according to the later calculations of the United States Coast and Geodetic Survey), and the mass of matter under any protuberant or depressed area from sea-level down to this depth is termed the supporting column of that area.

Now imagine the adjacent parts of an ocean and continent, in perfect isostatic equilibrium. Denudation removes material from the continent, which is deposited on the ocean bottom. Isostasy is disturbed, and if isostatic adjustment takes place the tendency will be for the continent to rise, the sea-floor to sink, and material in the depths to "flow" from the supporting column of the ocean into that of the continent. But how far can these movements go? The oceanic supporting column is composed, *ex hypothesi*, of material of more than average density; the material deposited, being unconsolidated sediment, is of less than average density. The former we

may estimate to have a density of 3. As to the latter, the average density of sedimentary material (making no allowance for porosity) is 2·7. Porosity to the extent of 20 per cent brings the density of unconsolidated *dry* sediment to about 2·16 (Indian geologists give 2·2 as the average for the Siwalik rocks, so 2·16 is not too low for quite unconsolidated material). But we have to deal with sediment saturated with sea-water to the extent of the 20 per cent of its volume allowed for porosity; this brings the density up to 2·36. The sediment, however, displaces sea-water as it accumulates, and though it thereby raises the sea-level, that rise, being distributed over the whole ocean, is negligible. The effective density for the calculation of isostatic overloading is therefore 1·36.

A mass of sediment on the sea-bottom, then, would depress the latter to the extent of $\frac{1\cdot36}{3}$, or about nine-twentieths of its own thickness, *if the isostatic adjustment is perfect and immediate.* Thus at whatever depth deposition begins a thickness equal to $\frac{3}{3-1\cdot36}$, or about 1·83 times that depth, could accumulate before the sea was completely silted up. Taking the 100-fathom line as the limit between deep and shallow water, shallow-water deposits could accumulate, under conditions of the most delicate isostatic adjustment, to a thickness of only about 1,100 feet before accumulation became inter-tidal or subaërial in character, and in that thickness there would be a gradual transition from deposits of 100-fathom type at the bottom to littoral deposits at the top. If we suppose the isostatic adjustment to be spasmodic instead of continuous, there will be an alternating character in the sediments instead of a gradual transition, but the total thickness will be, if anything, diminished, since the adjustment will be less perfect.

It may be objected that 3 is too high a figure for the density of the supporting column. If we take it at so improbably low a figure as 2·7, the maximum possible thickness is only increased from 1,100 to just over 1,200 feet.

But what right have we to assume such delicate isostatic adjustment as these calculations imply? The theory of isostasy originated in America, where the careful investigations of Hayford and the United States Coast and Geodetic Survey showed that there is an approximation to isostatic equilibrium—or, at least, that there is such on a certain assumption as to the depth of compensation. When Crosfield investigated India on the same assumption he found that country to diverge considerably from isostatic equilibrium. This was naturally explained by the immense crustal disturbances in that region, which, reaching a maximum in the Miocene period, have not yet entirely died out. If these great disturbances have not been capable of full isostatic adjustment in the long period of time that has elapsed since the Miocene period, can we justifiably assume that the gentle accumulation of sediment is continually and immediately adjusted?

Without venturing into any discussion of the complicated subject of the rigidity of the earth's crust, I may call attention to the view of Professor Barrell that the strength of the crust is "twenty, fifty,

or even a hundred times greater than that advanced in recent years by the champions of high isostasy".[1] If this opinion, the result of very careful mathematical studies, be put aside as a pendulum-swing in the opposite direction to that of the isostasy enthusiasts, the adoption of a mean position would still diminish our belief in the possibility of explaining great thicknesses of shallow-water deposits by the sole process of isostatic adjustment.

NOTICES OF MEMOIRS.

I.—A Hyæna-den in Ireland.

The Exploration of Castlepook Cave, County Cork: being the Third Report from the Committee appointed to explore Irish Caves. By R. F. Scharff, H. J. Seymour, and E. T. Newton. Proc. Roy. Irish Acad., vol. xxxiv, sect. B, No. 3, pp. 33–72, pls. v–vii, January, 1918.

THE last work of the accomplished and enthusiastic Irish cave-explorer, the late Mr. R. J. Ussher, was the careful examination of the Castlepook cave, co. Cork, which is of much interest as being further south than any cave previously dealt with in Ireland. It is formed as usual by the widening of joints in the Carboniferous Limestone, and the deposits on the floor consist not only of the ordinary cave-earth and stalagmite but also of sand and gravel introduced by water. The cave, in fact, must have been subjected to numerous inundations, and it can never have been suitable for habitation by man. As described by Professor H. J. Seymour, all the pebbles in the introduced gravel are of local origin, whereas many of those in the boulder-clay of the surrounding country are granites from a considerable distance. Some of the deposits containing bones may therefore be of pre-Glacial date. The lowest layer yields especially remains of a brown bear (*Ursus arctos*) as large as the American Grizzly—certainly not the familiar cave-bear. The next layer in some places is crowded with the bones, teeth, and coprolites of the cave-hyæna, with remains of the reindeer and the young mammoth which it dragged into the cave for food. The discovery of a hyæna-den in Ireland is especially interesting; and the proof that the hyæna and reindeer were contemporaneous is important. As might be expected, all the remains of the reindeer are very fragmentary; but Dr. R. F. Scharff, who reports on the mammals, has studied all the known Irish specimens of reindeer, including a fine skull from a bog near Ashbourne, co. Meath, and concludes that they represent a peculiar race which he names *Rangifer tarandus hibernicus*. Among truly Pleistocene mammals there are also the Arctic fox, wolf, hare, Scandinavian lemming, a new form of Arctic lemming, and the Irish deer. Numerous bones of birds, determined by Mr. E. T. Newton, also occur, but do not include any extinct or noteworthy species. A. S. W.

[1] "The Strength of the Earth's Crust": *Journ. Geol.* (Chicago), vol. xxii, p. 313, 1914. The whole investigation is in eleven sections, scattered through vols. xxii–iii, 1914–15.

II.—Fossil Man in South Africa.

1. Preliminary Note on the Ancient Human Skull-remains from the Transvaal. By S. H. Haughton. With notes appended on Fragments of Limb-bones, by R. B. Thomson, and Fragments of Stone, by L. Péringuey. Trans. Roy. Soc. S. Africa, vol. vi, pp. 1–14, pls. i–x, 1917.
2. Fossil Man in South Africa. By Robert Broom. American Museum Journal, vol. xvii, pp. 141–2, 1917.

WELL-FOSSILIZED portions of a human skeleton were discovered in 1913–14 in a cultivated field on the farm of Kolonies Plaats, Boskop, in the Potchefstroom district of the Transvaal. The greater part of a skull-cap, a temporal bone, the horizontal portion of the left mandibular ramus, and some fragments of limb-bones were recovered; but it is uncertain whether the remains represent a burial, and there are no associated fossils or implements to indicate their age. A preliminary description of these interesting specimens is now published and helps to dispel some of the sensational illusions which were derived from newspaper reports at the time of the discovery.

The skull is rather thick, its thickness at the parietal boss being 13 to 14 mm. Its brain-capacity is also remarkably large, probably not less than 1830 c.c. The cephalic index is about 75, so that the specimen is almost dolichocephalic. The forehead is steep, without prominent brow-ridges; but the temporal bone is primitive in the shallowness of the glenoid fossa for the mandibular articulation and the prominence of the supramastoid ridge. The mandible seems to have had a prominent bony chin, and the total length of the molar-series must have been as short as that of the modern European, less than that of the Australian. The second molar, typically modern human, is the only tooth preserved; and the alveoli of the other teeth are too imperfect to determine much of their proportions. On the whole, Mr. Haughton thinks it "possible that the Boskop man was a member of a race which ultimately developed into the Bantu type".

The limb-bones found with the skull are too imperfect for discussion, especially in their present encrusted state, and the three plates of photographs devoted to them are not illuminating. According to Dr. Péringuey, no stone implements have yet been met with at the same spot.

Dr. Broom expresses the opinion that the Boskop man is intermediate between *Eoanthropus* and the early African type of man. In fact, he considers there is "no doubt that the canine was about as large as in the jaw which he still believes belongs to the Piltdown skull". He also thinks the incisors were much larger than in modern man. Mr. Haughton's description and figures, however, lend no support to these views.

A. S. W.

III.—The Bearing of the Facts revealed by Antarctic Research upon the Problems of the Ice Age.[1] By Marsden Manson, C.E., Ph.D., Mem. Amer. Soc. C. E., San Francisco, California. From *Science*, N.S., vol. xlvi, No. 1200, pp. 639–40.

RECENT Antarctic explorations and researches have yielded significant evidence regarding the problems of the Ice Age, and of the similarity of the succession of geological climates in polar with those in other latitudes.[2]

These researches have been prosecuted to the ultimate limit of courage, devotion to duty, and endurance—the noble sacrifice of life—as in the cases of Captain Scott, R.N., and his devoted companions and members of the expedition of Sir Ernest Shackleton.

The data secured by these expeditions are alone sufficient to establish the following premises:—

1. That Antarctic ice, although covering areas several times larger than all other ice-covered areas, is slowly decreasing in extent and depth.

2. That the same succession of geological climates have prevailed in Antarctic as in other latitudes.[3]

So vital are these evidences of the retreat of Antarctic ice that it may be well to briefly quote or refer to the most prominent instances: "All these evidences and many others which space will not allow me to mention lead up to one great fact—namely, that the glaciation of the Antarctic regions is receding.[4] The ice is everywhere retreating.[5] The high level moraines decrease in height above the present surface of the ice, the débris being two thousand feet up near the coast and only two hundred feet above near the plateau. (Scott's lecture on the great ice barrier.[6])"

This observation applies to an ice-covered area of over 116,000 square miles.

Mr. Griffith Taylor notes the recession of Dry Valley Glacier twenty miles from the sea below Taylor Glacier.[7]

Mr. Taylor also notes and speaks with confidence of the passage of the Ice Age from Antarctica.[8]

In speaking of the evidence of ice retreat over Antarctic areas

[1] This term as used by the writer refers to the Great Ice Age of Pleistocene time. He holds that the occurrences of ice as a geologic agent of magnitude during eras preceding the Pleistocene were not "worldwide" nor as "phenomenal", nor were they preceded, accompanied, nor followed by conditions as significant as corresponding phenomena of the Ice Age. Compte Rendu du XIème Congrès Géologique International, Stockholm, 1910, p. 1105.

[2] *Scott's Last Expedition*, vol. ii, p. 206.

[3] This part of the evidence is not considered in this paper except inferentially as bearing upon the general subject.

[4] Scott, *The Voyage of the "Discovery"*, vol. ii, p. 416. See also pp. 423–5, and sketch-map of ice distribution, p. 448.

[5] Scott, *National Antarctic Expedition, 1900–1904*, vol. i, p. 94.

[6] *Scott's Last Expedition*, vol. ii, p. 294.

[7] Ibid., p. 286.

[8] Ibid., p. 288. See also photograph following pp. 286, 292.

explored by him, Sir Ernest Shackleton said: "Some time in the future these lands will be of use to humanity."[1]

This impressive and conclusive evidence is corroborated by the greater and still more impressive evidences of the comparatively recent uncovering of temperate land areas,[2] and the progressive retreat of the snow-line to higher elevations in temperate and tropical latitudes and towards the poles at sea-level, being far greater in Arctic than in Antarctic regions. We are therefore confronted with the conclusions—

1. That the disappearance of the Ice Age is an active present process and must be accounted for by activities and energies now at work, and that the use of assumptions and hypotheses is not permissible.

2. That the rates and lines of retreat are and have been determined by exposure to solar energy and the temperatures established thereby; and by the difference in the specific heat of the land and water hemispheres.

3. That the lines of the disappearance of ice are not conformable with those of its deposition, and mark a distinctly different exposure and climatic control from that which prevailed prior to the culmination of the Ice Age.

4. This retreat also marks a rise in mean surface temperature along these new lines, manifestly due to recently inaugurated exposure to solar radiation and also the inauguration of the trapping of heat derived from such exposure; which process is cumulative and has a maximum not yet reached.

The researches under the direction of Captain Scott and Sir Ernest Shackleton have therefore very rigidly conditioned any inquiry as to the causes of glacial accumulation and retreat. These conditions are CORRECTIVE and DIRECTIVE—*corrective*, in that they have entirely removed any doubts as to the alternate glaciation of the poles under the alternate occurrence of aphelion and perihelion polar winters by the precession of the equinoxes, as advanced by Croll; *directive*, in that they have imposed an appeal to energies now active as causes of retreat, and divested the problem of resorts to the fascinating but dangerous uses of suppositions and hypotheses.

They have, moreover, pointed out with unerring accuracy the vital conclusion that the same energies which have but recently converted the glacial lake beds of Canada into the most productive grain fields of the world will in time convert the tundras of to-day into the grain fields of to-morrow.[3]

[1] Address to the Commonwealth Club, San Francisco, Calif., November 7, 1916.

[2] Slight fluctuations in the retreat of the small residual glaciers in temperate latitudes are noted in the reports of the Commission on Glaciers of the International Geological Congress by Professor Harry Fielding Reid. But the great measures of the progressiveness of glacial retreat are in the past disappearance of the Pleistocene ice-fields of temperate latitudes and the present retreat in the Antarctic and Arctic regions.

[3] See also Compte Rendu du XIème Congrès Géologique International, Stockholm, 1910, p. 1102.

The bearing of this conclusion upon the ultimate development of the human race is so far-reaching in its consequences that the great sacrifice of life attendant upon the prosecution of these researches stands forever as a memorial in the correction of the erroneous and widespread conception that the earth is in a period of refrigeration, desiccation, and decay; and establishes the conclusion that it is in the springtime of a new climatic control during which the areas fitted for man's uses are being extended and that the moss of polar wastes will be replaced by rye and wheat.

IV.—John Michell and Martin Simpson.

SIR ARCHIBALD GEIKIE read as his Presidential Address to the Yorkshire Union of Naturalists, 1917, a memoir on John Michell (1724–93), one of the pioneer geologists of this country. The memoir, written in Sir Archibald's delightful style, appears in full in the *Yorkshire Naturalist* for January, 1918.

Mr. Thomas Sheppard, remembered recently for his able memoir on William Smith, read to the Yorkshire Geological Society a paper on Martin Simpson (1800–92) (see Geol. Mag., February, 1918, p. 82).

REVIEWS.

I.—Sands used in Manufactures.

1. A Memoir on British Resources of Sands suitable for Glass-making, with Notes on certain Crushed Rocks and Refractory Materials. By P. G. H. Boswell. pp. 92. London: Longmans, Green & Co. 1916.
2. A Supplementary Memoir on British Resources of Sands and Rocks used in Glass-manufacture, with Notes on certain Refractory Materials. By P. G. H. Boswell. pp. 92. London: Longmans, Green & Co. 1917.
3. British Glass-sands; their Location and Characteristics. By P. G. H. Boswell. From the Transactions of the Society of Glass Technology, vol. i, 1917.
4. Notes on American High-grade Glass-sands. By P. G. H. Boswell. From the Transactions of the Society of Glass Technology, vol. i, 1917.
5. Some Geological Characters of Moulding-sands. By P. G. H. Boswell. Reprinted from the *Foundry Trade Journal*, August, 1917.
6. Sands used in Metallurgical Practice, with Comparative Notes on those used in Glass-manufacture. By P. G. H. Boswell. Reprinted from the Journal of the Society of Chemical Industry, 1917.

THE petrology of the sedimentary rocks is a subject that has been unduly neglected until recent times. Considerable attention was devoted to the matter by Professor Bonney, mainly in connexion with cemented types which could be studied in their slices. The early investigations of Retgers, Dick, Thoulet, Bréon, and others may

also be mentioned, but the study on modern lines of the unconsolidated sediments may be said to date from the classical work of Dr. Thomas on the Trias sands of the West of England. Since then much work of high scientific value has been carried out by Mr. Crook, Mr. Bosworth, and other. As is well known, Professor Boswell has made an extensive study of the mineral constitution of sediments, and when the investigation of sands became a matter of urgent practical importance his knowledge of methods and technique rendered most valuable service. The six publications above cited contain the results of work carried out by him at the instance of the Ministry of Munitions. The first on the list has already been reviewed in these pages and is only included here for the sake of completeness.

On the outbreak of war a large part of the imported supplies of sand and other similar materials failed, and manufacturers were driven by sheer necessity to inquire into the British resources that might be available to replace them. Sand is used on a large scale for many industrial purposes: in metallurgy it is employed for moulding and as a refractory material; it is the fundamental necessity of glass-making, and it is also used for building, for filtration, as an abrasive, and for many other purposes. The author describes very fully the characters essential for each particular purpose. For glass-making the criterion is purity: a sand adapted for high quality glass should consist as nearly as possible of pure quartz, while what are commonly known as "heavy minerals" should be in the smallest possible quantity. Iron compounds spoil the colour, while such infusible substances as zircon and rutile produce flaws. Recent research has shown that the presence of a small amount of alumina is not really deleterious, hence felspar up to a certain proportion is not objectionable. Evenness of grain is also important, since it leads to uniform and regular fusion. The requisites for a moulding sand are that it should consist mainly of fairly large grains with a sufficient amount of very fine binding material, thus having a large water-holding capacity. The sands of the Trias best fulfil these requirements. Other sands are now often employed with an artificial binding material.

No British glass sands are quite equal in quality to the very best imported kinds, such as those of Fontainebleau and Lippe, but we possess material suitable for even the best kinds of optical glass, while our reserves of sand available for common glass are practically inexhaustible.

The properties of a sand depend on several factors, of which the most important are chemical and mineralogical composition and texture. The first two are obviously interdependent, and in their investigation the methods devised for geological purposes are of the utmost value. The texture, which is equivalent to size of grain, is determined by mechanical analysis, using the methods devised for the study of agricultural soils. It is clearly shown that the state of division is a matter of the greatest practical importance, since it controls to a very large extent the physical properties on which so much of the value of the sand for metallurgical purposes depends.

Very large quantities of sands, crushed rocks, clays, and other similar materials are also employed as what may be called for convenience "refractories" in many industrial processes carried on at high temperatures. This subject is dealt with briefly by Professor Boswell. It is known, however, that an investigation on a large scale of British resources of refractories has been carried out by the Geological Survey, and the publication of their results will be awaited with much interest.

It is apparent that the detailed study of sands, undertaken originally for purely geological purposes, has proved of great practical and economic use, thus affording one more instance, if one were needed, of the ultimate value of pure science for industrial ends, a fact which has long been recognized and acted on in Germany, but which the people of this country are only just beginning to realize.

R. H. R.

II.—Report on the Phosphates of Saldanha Bay. By A. L. du Toit. Memoir 10, Geological Survey of the Union of South Africa. pp. 34, with a map. Pretoria, 1917. Price 2*s.* 6*d.*

THE region described in this report lies on the west coast of Cape Colony: the country consists of granite, quartz-porphyry, surface limestones, and blown sand. Along the coast are raised beaches. In connexion with these a small quantity of good quality phosphorite has been located, while in addition there are great masses of phosphate of alumina and iron of much less agricultural value. It is hoped that a special method of treatment that has been devised will enable this phosphate to be used as a fertilizer. The origin of the phosphate is interesting. It is due to the percolation of solutions from guano into limestones, shell-beds of the raised beaches, and other detrital deposits. Even boulders and chips of granite and porphyry are more or less phosphatized. The whole phenomenon is compared by the author with Sir J. J. H. Teall's classical description of Clipperton Atoll, where a trachyte has been phosphatized by a similar process.

R. H. R.

III.—Report on the Building and Ornamental Stones of Canada. Vol. IV: Provinces of Manitoba, Saskatchewan, and Alberta. By William A. Parks. pp. xiv+333, with 56 plates and 7 drawings and maps. Ottawa: Government Printing Bureau, 1916.

THIS, the fourth, volume of the excellent series of reports on the building and ornamental stones of Canada which is issued under the auspices of the Canadian Department of Mines, deals with the products of the three provinces of Manitoba, Saskatchewan, and Alberta, and is from the pen of Dr. W. A. Parks. As he states in the letter of transmittal to the Director of the Mines Branch, in the earlier volumes attention was paid only to actual quarries, whereas in the present one the scope has been enlarged so as to include possible sources of supply which have not yet been exploited, and "in consequence of this change of plan the report has reached

a length, compared with the earlier volumes, which is somewhat out of proportion to the relative importance of the building stone industry in the three Provinces under consideration".

In the opening chapter the author gives a general account of the building stones of the three provinces, and briefly explains the nature of the physical tests to which the several samples have been subjected in order to ascertain their suitability for the purpose and their capacity to withstand weathering. The determinations made included the specific gravity, weight per cubic foot, porosity, ratio of absorption, coefficient of saturation, crushing tests (dry, wet, and frozen), transverse and shearing strength tests, and corrosion, drilling, and chiselling tests. In the corrosion test cubes of the stone under investigation were suspended in water through which carbonic acid gas and oxygen were passed, and the whole operation took four weeks, the water being changed twice weekly. Mr. MacLean, who was in charge of this part of the investigation, discovered that the rate of solution of limestone was materially affected by the pressure maintained in the containing bottle, and he devised special apparatus for keeping the pressure constant. The provinces in question do not as yet yield much diversity of building stone, the present supply being confined to the mottled limestones of Tyndall in Manitoba and the Paskapoo Sandstones of Alberta, but there are possibilities of other occurrences of these stones being worked as soon as the demand justifies it. The eastern ranges of the Rocky Mountains, which come within the scope of the book, cannot be drawn upon for building stone to any great extent, because the limestone of which they chiefly consist is so hard and shattered as to be unsuitable for the purpose.

A concise discussion of the geology of the region is the subject of the following chapter. As is well known, its most conspicuous physical character is found in the great prairie plains which stretch from the rocky district of the Manitoba lakes and Lake Winnipeg on the east to the foothills of the Rocky Mountains on the west, and building stone can only be looked for on the margin of the plains owing to the thickness of the soil over the whole of them. In the remaining eight chapters the various rocks furnishing building stones are considered in detail, commencing with the limestones and sandstones, and passing on to the miscellaneous rocks and ornamental stones; while the physical characters of the stones and statistical data are tabulated in appendices.

The Tyndall Limestone has been used for such important buildings as the Parliament buildings at Regina and the Post Office at Moose Jaw in Saskatchewan, and the Post Office at Lethbridge in Alberta; while the Paskapoo Sandstone has been selected for the Court House at Lethbridge, the Royal Bank at Medicine Hat, the Court House and Parliament buildings at Edmonton, Knox Church, the Land Titles building, City Hall, and the Carnegie Public Library at Calgary, in the province of Alberta. Photographs of all these buildings are included among the numerous illustrations. There are also six plates in colour showing sections of limestone, granite, and sandstone.

IV.—The Geology of Part of the Transkei. Explanation of Sheet 27, (Cape) Maclear—Umtata. By A. L. du Toit; with an introduction by A. W. Rogers, Geological Survey. pp. 32. Pretoria, 1917. Price 2*s.* 6*d.*

THIS memoir is to accompany the map on the scale of 3·75 miles to an inch, prepared by Dr. du Toit. The map contains a very large amount of detail, considering the character of the country, which includes part of the great Drakensberg escarpment and rises to a height of some 9,000 feet. The area surveyed is entirely composed of the rocks of the Karroo system and their accompanying lavas, ashes, and intrusions. The whole of the Karroo system is represented and reaches the great thickness of 14,000 feet, exclusive of the Stormberg lavas, which are about 3,000 feet more. The strata are normal in character and contain plants and reptiles, hence horizons can now be fixed with fair accuracy, since it has been found possible to establish reptile zones in this formation. Some coal-seams of workable thickness are found in the Molteno beds. A considerable number of volcanic necks have been located, and the Karroo dolerites have been intruded on an enormous scale, chiefly in the Ecca and Beaufort series.

Perhaps the most interesting part of the memoir is the description of the copper-nickel bearing area of Insizwa and Tabankulu. The ores occur at the lower contact of great cakes of gabbro-norite, a special phase of the Karroo dolerites, intruded into the lower division of the Beaufort beds. These masses, which are about 3,000 feet thick, have undergone magmatic differentiation by gravity, the lower part being a picrite, followed by olivine-norite and norite; at the top there is even a little quartz as micropegmatite. The Insizwa mass is some ten miles in diameter. The ores occur at the base of the intrusion and also to a certain extent in the country rock close to the contact. The principal minerals are pyrrhotite, chalcopyrite, and pentlandite, with smaller amounts of niccolite and bornite and some oxidized copper and nickel minerals. Platinum has been found by assay up to 1 oz. per ton, but it is not yet known in what form it occurs. There is also a little gold. The ores were undoubtedly formed by differentiation from the norite magma, and the whole occurrence is very similar to the famous nickel deposits of Sudbury, in Ontario. From the geological relations it appears highly probable that the amount of ore will increase in depth when followed below the intrusion. The deposits are now being actively developed, and it seems probable that they will eventually prove to be of great commercial value.

R. H. R.

V.—Low-temperature Formation of Alkaline Felspar in Limestone. By R. A. Daly. Proceedings of the National Academy of Sciences, vol. iii, pp. 659–65, 1917.

AUTHIGENIC crystals of felspar, including orthoclase, albite, and perhaps microcline, have been described by various authors in the Jurassic limestones of the Alps and in the Chalk of the Paris Basin. The crystals are well-shaped, but very minute, and are

supposed to have been formed on the sea-floor during the deposition of the sediment: in the case of the Paris Basin, at any rate, thermal metamorphism is excluded. With these observations Mr. Daly compares a remarkable dolomite in Alberta, probably of Pre-Cambrian age. It consists chiefly of grains of carbonate of rhombohedral form, but certain layers are heavily charged with clumps and interlocking grains of glass-clear orthoclase, from 0·01 to 0·05 mm. in diameter, and without good crystal form. The total amount of felspar is estimated at 37 per cent of the rock. It is suggested that these crystals were also developed during the deposition of the sediment at the ordinary temperature.

R. H. R.

REPORTS AND PROCEEDINGS.

I.—Geological Society of London.

1. *January* 9, 1918.—Dr. Alfred Harker, F.R.S., President, in the Chair.

The following communication was read:—

"The Highest Silurian Rocks of the Clun Forest District (Shropshire)." By Laurence Dudley Stamp, B.Sc., A.K.C.L. (Communicated by Dr. A. H. Cox, F.G.S.)

Clun Forest is a large district—extending on both sides of the Welsh Border—in which Upper Silurian rocks crop out over a wide area, interrupted by outliers of Old Red Sandstone. The district is separated from the typical Silurian area of Ludlow, which lies some 15 miles away to the east, by the great line of disturbance that passes through Church Stretton and Old Radnor.

The classification adopted for the highest Silurian strata is as follows:—

			Thickness in feet.	
Old Red Sandstone				Purplish-red sandstones.
Temeside Group.	Temeside Shales		350	Olive-green shales with bands of micaceous green grit; a fragment-bed, with Eurypterid and plant remains, forms the upper limit.
	Downton Castle Sandstone Series.		110	Yellow sandstones and tilestones, with shales and *Platyschisma* Limestones.
Upper Ludlow Group.	*Chonetes* Beds	Upper	50	Green laminated flags and blue flagstones.
		Lower	300	Irregularly bedded calcareous flagstones.
	Rhynchonella Beds		300	Grey calcareous flags with massive blue flagstones.
Aymestry Group.	*Dayia* Shales		?300	Striped laminated shales and mudstones.
	Lower Ludlow Shales			Dark-grey shales and indurated mudstones.
	Total		1410	

The distribution and characters of the beds are described. The succession compares very closely with that in the Ludlow district

itself. The main differences are: (1) that the Aymestry Limestone is represented by mudstones west of the great fault-line, and (2) that all other divisions show greatly increased thicknesses.

There is no evidence of any stratigraphical break. On the contrary, the sequence is complete from the Lower Ludlow rocks up into the Old Red Sandstone, and the changes in lithology are usually quite gradual. The oncoming of the Old Red Sandstone conditions is discussed, with regard to their effect on the lithological and palæontological characters of the strata.

The extent of Old Red Sandstone, as indicated on present maps, must be greatly restricted, since most of the supposed Old Red Sandstone has been found to belong to the Temeside Group, which in this district attains a great development. The Silurian age of the beds in question is shown by the occurrence in them of *Lingula minima*, and of characteristic Lamellibranchs, etc., also by comparison with similar strata in the Ludlow area.

A comparison with other districts in which Upper Silurian rocks are developed shows that deposition attained its maximum along the Welsh Border, the thickness of the formations decreasing rapidly southwards and eastwards.

On the east of the district, in the neighbourhood of the great fault-line, the strata are considerably folded along axes ranging north-north-eastwards, parallel to the main fault, with minor faults following the same direction. Away from the major faults the folding is gentler in character, and a series of folds ranging nearly due east and west make their appearance. Farther west the north-north-eastward folding and fracturing reappear.

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2. *January* 23, 1918.—Dr. Alfred Harker, F.R.S., President, in the Chair.

The following communication was read:—

"On a Flaked Flint from the Red Crag." By Professor William Johnson Sollas, M.A., Sc.D., LL.D., F.R.S., V.P.G.S.

The remarkable specimen forming the subject of the paper was obtained by Mr. Reid Moir from the base of the Red Crag exposed in the brick-pit worked by Messrs. Bolton & Company near Ipswich.

It is a fragment of a nodule of chalk-flint, irregularly rhombic in outline, with a nearly flat base and a rounded upper surface which retains the whitish weathered crust of the original nodule.

The base was formed by a natural fracture which exposes the fresh flint bordered by its weathered crust.

Both upper and under surfaces of the specimen are scored with scratches which are mainly straight, but in some cases curvilinear.

Two adjacent sides have been flaked by a force acting from below upwards, in a manner that recalls Aurignacian or Neolithic workmanship. The two edges in which the flaked faces meet the base are marked by irregular minute and secondary chipping, such as might be produced by use. On the hypothesis that the flint has been flaked by design, these edges will correspond to the "surface d'utilisation" of M. Rutôt, and we should expect to find on the opposite edges of the flint the "surface d'accommodation", as in fact we do.

A singular feature, which seems difficult to reconcile with its use as an implement, is the restriction of the flaking on one edge to the weathered crust.

The origin of the flaking is discussed, and the author, while admitting that the fashioning of the flint is not inconsistent with intelligent design, concludes that the evidence is not sufficient to establish this beyond dispute. It is eminently a case of "not proven".

The Secretary read a letter from Mr. J. Reid Moir, in which he stated that the flint in question was found by him in the detritus-bed below the decalcified Crag in the brickfield of Messrs. Bolton and Co., Henley Road, Ipswich, and that the author at first accepted the specimen as being of undeniable human origin. Mr. Reid Moir further expressed the opinion that the flaking to be seen upon the specimen was "human" in its characteristics, and referred to his printed papers in support of that opinion.

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3. *February* 6, 1918.—Dr. Alfred Harker, F.R.S., President, in the Chair.

The following communication was read:—

"Some Considerations arising from the Frequency of Earthquakes." By Richard Dixon Oldham, F.R.S., F.G.S.

The publication[1] of an abstract of twenty years' record of earthquakes in Italy gives an opportunity for studying the effect of the gravitational attraction of the sun; the period is so nearly coincident with the lunar cycles of 19 and 18·6 years that the effect of the moon may be regarded as eliminated, the record is of exceptional continuity and completeness, and the number of observations is large enough to allow of the extraction of groups sufficiently numerous to give good averages.

The distribution of the stresses is dealt with in textbooks; there is a maximum upward stress, in diminution of the earth's attraction at its surface, at the two points where the sun is in the zenith or nadir, and a maximum downward stress along the great circle where it is on the horizon; but as, for the purpose of this investigation, a decrease of downward pressure is equivalent to an increase of upward, I shall take the line along which the downward stress is greatest as the zero-line, and express the amount of stress at any other time or place as a fraction of the difference between the net force of gravity along this line and at the point where the sun is in the zenith. The fraction, at any given time and place, depends solely on the zenith distance of the sun, which is continually varying with the revolution of the earth. At the equinox, when the sun is on the equator, the curve of variation between 6 a.m. and 6 p.m. is the same as in the other half of the day; at any other part of the year it is not symmetrical in the two halves of the day, but is the same during the day in the summer half of the year as during the night in the corresponding part of the winter half, when the declination of the sun is equal in amount, though opposite in direction.

[1] Boll. Soc. Sismol. Italiana, vol. xx, p. 30, 1916.

This gave the first suggestion for grouping the records. The year was divided into two halves by the equinoxes, and the day into two halves, at six hours before or after noon, called day and night for convenience, irrespective of the time of sunrise or sunset. The result is given in the tabular statement below, the frequency being expressed as a ratio to the mean, of each group, taken as 100 :—

DISTRIBUTION OF SHOCKS BY DAY AND NIGHT.

	Day.	*Night.*
Italy, 1891–1910.		
June–July	90 :	110
Summer half	88 :	112
Whole year	84 :	116
Winter half	81 :	119
December–January	77 :	123
Japan, 1885–1892.		
Summer half	102 :	98
Whole year	97 :	103
Winter half	93 :	107
Assam Aftershocks.		
Summer half	113 :	87
Whole year	107 :	93
Winter half	101 :	99

From this statement it will be seen that the mean ratio of day to night shocks over the whole period is represented by the figures 84 : 116; for the summer half of the year they become 88 : 112, and for the winter half 81 : 119, showing that during the day the shocks are somewhat less frequent in the winter, with an opposite variation during the night. Taken by itself this difference might be merely fortuitous, and further confirmation is required: this can be got in two ways. In the first place by comparison with other records, two of which, Milne's catalogue of Japanese earthquakes from 1885 to 1892[1] and the aftershocks of the Indian earthquake of 1897,[2] stood ready for use. They show a variation identical in character with that of the Italian record. A second test depends on the argument that, if the variation is in any way seasonal, the divergence should be increased at the height of each season; the figures for the months of January–February and of June–July were taken out, as representing midwinter and midsummer respectively, and found to show a divergence in each case greater than, and in the same direction as, the respective half-years.

Taken by itself the variation, as between any pair of ratios, is as likely to be in one direction as in the other, but the odds against a complete concordance throughout the whole series is 31 to 1; there is, therefore, a strong presumption that the variations are not fortuitous, but due to some common cause which tends to increase the frequency during the day and decrease it during the night in summer, with the opposite in winter.

The variation in the frequency of earthquakes may, or may not, be connected with the variation in the gravitational stresses due to the sun; but there is another line of investigation by which a connexion may be better traced, dependent on the fact that the prevailing effect of the vertical stress is in the direction of lightening

[1] Seismol. Journ. Japan, vol. iv, 1895.

[2] Mem. Geol. Surv. India, vol. xxxv, pt. ii, 1903.

the load, and the prevailing direction of the horizontal stress between east and south, during the six hours before the meridian passages at noon and midnight, and of an increase in the downward pressure and a horizontal stress between south and west during the next six hours. The record was accordingly grouped by the successive two-hour periods from XII to XII o'clock, and the mean amount of variation in the stresses was calculated for the same periods. The result is set forth in the appended tabular statement:—

DISTRIBUTION OF STRESSES AND SHOCKS IN TWO-HOUR PERIODS, BEFORE AND AFTER MIDDAY AND MIDNIGHT.

Hours . . .	XII	II	IIII	VI	VIII	X	XII
STRESSES.							
Mean range of stress in each two-hours, in Italy.							
Total stress . . .	−·10	−·27	−·23	+·23	+·27	+·10	
Horizontal component . .	+·07	−·11	−·20	+·20	+·11	−·07	
Vertical component . .	−·14	−·27	−·13	+·13	+·27	+·14	
SHOCKS.							
Ratio of actual to mean frequency of each two-hour period.							
ITALY, 1891–1910 . .	1·06	1·17	1·01	·90	·88	·99	
JAPAN, Aftershocks of Mino-Owari, October 28, 1891 .	1·01	·95	·96	·97	1·08	1·03	
JAPAN, 1885–90 . . .	1·00	1·11	·89	·98	1·03	·99	

From these figures it is seen that, while there is no apparent relation between the frequency and the total, or the horizontal, stress, there is a close one with the variation of the vertical stress; the greatest number of earthquakes being in the period in which there is the greatest increase of downward pressure; as the rate of increase diminishes the number of shocks is less, suffering a further diminution as the pressure begins to decrease, and reaching its minimum in the period where the decrease in pressure is greatest, increasing again in the same way to the maximum.

An attempt to apply the same method to the Japan record gave a result which was, at first sight, contradictory and also inconsistent in itself, for it gave an absolute maximum at the time when the Italian gave a minimum, with another maximum, almost as great, in coincidence with the Italian; but, in any comparison, it is necessary to allow for the contrast in the character of the two records. The Italian does not contain more than two, or at most three, great earthquakes of the type that gives rise to long-distance records (bathyseisms), and the aftershocks account for no more than a quarter of the whole record; the Japanese record, on the other hand, is dominated by bathyseisms and aftershocks. Not only does the region give origin to an unusually large number of teleseisms, or

bathyseisms, but aftershocks form fully three-quarters of the record, and nearly a half consists of aftershocks of the Mino-Owari earthquake of October 28, 1891. Taking these separately, we get a curve of frequency similar to the Italian, except that the maximum and minimum are reversed, the greatest number of shocks corresponding to the period when the load is being lightened most rapidly, indicating that these shocks are due to a general movement of elevation rather than depression, a conclusion in accord with field observations of other great earthquakes. In addition, the shocks which occurred during the period 1885–90 were taken out, as representing a more normal activity, though still one in which aftershocks form fully half of the record, and the curve was found, as might have been expected from the character of the record, to combine the features of the Mino-Owari aftershocks with those of the Italian curve of frequency, of earthquakes prevailingly of the so-called "tectonic" type.

These results are of twofold geological interest. In the first place they confirm the conclusion drawn from a study of the Californian earthquake of 1906,[1] that the great earthquakes differ from the ordinary, not merely in degree but in kind. They indicate that in the latter the main stress is compressive, probably due to settlement, and in the former to elevation or tension, a conclusion which is in accord with the fact that, in those cases in which it has been possible to compare accurate measurements made before and after the earthquake, the comparison has indicated an expansion, elevation, or both, of the area affected by the disturbance.

The second point of interest is that the figures give a means of estimating the rate of growth of the strain which produces earthquakes. If we accept the hypothesis that earthquakes, in the limited sense of their orchesis, are due to the relief by fracture of a growing strain when this has reached the breaking point, it can be easily shown that a variable strain, acting in alternate periods in increase or decrease of the general growth of strain, while leaving the average rate unaltered, will give rise to a corresponding variation in the frequency of shocks in each period; and, besides that, there is a simple relation between the magnitudes of the two stresses, to which the strains are due, and the variations from the mean frequency of earthquakes. A calculation on these lines shows that the growth of strain, for Italy, is such that, accepting the published estimates that an area of the earth's crust of the magnitude of Italy would crush under its own weight if left unsupported to the extent of $\frac{1}{400}$ of the force of gravity, the breaking strain would be reached in about $3\frac{1}{2}$ years, starting from a condition of no strain. The aftershocks of the Mino-Owari earthquake give a little less than half this figure, which is again reduced to from five to six months if account is taken of the difference between the resistance of rock to tension and to compression. These figures are given for what they are worth; at the least, they are of interest as being the first authentic estimate which it has been possible to make of the time required to prepare for, and, thence, of the rate of growth of the particular tectonic process involved in the production of earthquakes.

[1] Q.J.G.S., vol. lxv, p. 14, 1909.

4. *February* 20, 1918.—George William Lamplugh, F.R.S., President, in the Chair.

The following communication was read:—

"The Geological Aspects of the Coral Reef Problem." By Professor William Morris Davis, For. Corr. G.S.

The communication is a critical review of the various theories that have been put forward up to the present time to explain the origin of coral reefs. A voyage in the Pacific, made in the year 1914, enabled the author to collect new evidence bearing upon the question, and to make observations that have influenced him in his support of Darwin's theory.

After laying stress upon the embayment of shore-lines as a proof of subsidence, the author expresses the opinion that all theories that postulate a fixed relation between reef formation and ocean level are disproved, and are probably inapplicable to the case of atolls. It appears certain that reef upgrowth is intimately associated with submergence wherever the matter can be tested. The solution of the coral reef problem turns at present upon some means of discriminating between a submergence caused by subsidence and a submergence caused either by a general rise of the ocean level due to the uplift of the ocean floor beyond the coral reef region or to the melting of the Pleistocene ice-sheets. Although no means of such discrimination are known, the author presents reasons that lead him to regard changes in ocean level as of secondary importance, and that have caused him to attribute the submergence demanded by self-encircled islands to local subsidence, in accordance with the views of Darwin and Dana. He regards the theory that presupposes the raising of the ocean level by uplift as extravagant in its demands, and he finds the theory of "Glacial Control" inadequate when applied to barrier reefs and encircled islands.

Stress is laid on the highly significant unconformable relationship that exists between reef and lagoon limestones and their foundations —a feature that presents the strongest testimony for subsidence. In such a case the foundations must have suffered erosion for a considerable period before they were submerged, in preparation for the unconformable deposition of reef limestones upon them. From a consideration of such unconformable relations it is concluded that fringing reefs do not mark stationary or rising islands as generally as Darwin supposed.

With regard to elevated reefs, the author demonstrates the impossibility of explaining their features by regarding them as having been stationary while the ocean surface was lowered, and holds that they must be due to local and diverse uplift affecting the islands themselves, following on epochs of subsidence which were the epochs of reef formation. The theory that such reefs were formed during pauses in the elevation and emergence is considered to be seriously defective, and is contrary to Darwin's views.

The author discusses the studies of Semper on the reefs of the Pelew Islands, the origin of atolls as propounded by Rein, the views of Murray on barrier reefs and atolls, and of Wharton on the truncation of atoll foundations; but forms the opinion that the

geological evidence for subsidence has been overlooked by these investigators, who paid no attention to the evidence afforded by unconformable contacts or embayed shore-lines.

The author feels that scientific opinion in regard to the origin of coral reefs has been guided rather by subjective preference than by objective logic. He considers that Darwin's theory of intermittent subsidence is the most competent to explain the facts, and while he holds that other theories than Darwin's deserve cordial consideration, he feels that the burden of proof should be laid upon those who assume that reef foundations have not subsided.

II.—Edinburgh Geological Society.

January 16, 1918.—Professor Jehu, President, in the Chair.

"The Supplies in Scotland of Felspars suitable for Industrial Purposes." By Dr. Campbell.

Recent investigations of Scottish sources of alkali felspars had been necessitated by (1) the difficulty of obtaining shipment of the Scandinavian "spar", which is used extensively in the enamel, glass, and pottery industries, and (2) the possibility of utilizing potash felspars as a source of soluble potash salts, hitherto imported from Germany.

Dr. Campbell gave an account of the results so far obtained of an inquiry carried out by Mr. Dinham and himself on behalf of the Geological Survey of Scotland. Pegmatites, the chief source of alkali felspars, were described from Beinn Ceannabeinne, the district between Lochs Laxford and Inchard, Rhiconich, and Overscaig in Sutherlandshire, from the Strontian district of Argyllshire, from Portsoy, Banffshire, and from Monymusk, Aberdeenshire. It was shown that, from their high content of silica and iron oxides, many of the Scottish pegmatites would be classed as spar of Grade 3. There were, however, abundant supplies of spar of Grade 2, and at a few localities, particularly at Rhiconich, Strontian, and Monymusk, spar of Grade 1 (equal to the best Scandinavian spar) could be made available by hand-picking. Analyses of the average material of the best pegmatites gave potash content ranging from 7·42 to 9·35 per cent. The red potash spar at Rhiconich was found to be associated with a buff-coloured spar containing 7·13 per cent of soda, which might be separated by hand-picking and utilized in the glass industry. Estimates were given of the quantity of spar available at each locality. The most extensive deposits are those at Beinn Ceannabeinne, where at least 12,000,000 tons could be obtained by open-cast working.

Certain highly felspathic granites and felsites were regarded also as likely to be of economic value. Of the granites examined, the well-known Corrennie granite of Aberdeenshire was most promising. An average sample of the rock yielded 8·02 per cent of potash, and the only ferro-magnesian mineral present, biotite, occurs very sparingly. The spoil heaps in the quarries would furnish an immediate supply of many thousands of tons, and for practical purposes the available supplies might be regarded as "unlimited".